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PATENT

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APPLICATION FOR LETTERS PATENT

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INVENTION	:	LIGHT SOURCE FOR OPEN-PATH GAS MONITORING
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TO ALL WHOM IT MAY CONCERN:

Be it known that we, Stuart F. Metcalfe and Derek D. Stuart, citizens of the United Kingdom, residing in South Yorkshire and Derbyshire, respectively, have made a certain new and useful invention in a LIGHT SOURCE FOR OPEN-PATH GAS MONITORING, of which the following is a specification:

SPECIFICATION

RELATED APPLICATIONS

This application claims priority from British patent application No. 0120588.9 filed on August 24, 2001 under 35 U.S.C.§119.

FIELD OF THE INVENTION

The invention pertains to a light source used for open-path gas monitoring, particularly for the measurement of the smoke and dust content of stack gases, but also applicable to the measurement of particulates in the atmosphere.

BACKGROUND OF INVENTION

The standard method for continuous emissions measurement of particulates in stacks and ducts is optical transmissometry. The measured quantity is opacity, defined as the fraction of transmitted light which is lost in transmission through a medium.

One example of a device that measures opacity, known as a transmissometer, is the Land Combustion Model 4500mkII opacity monitor which has been used for a number of years to measure the opacity of gases in stacks and ducts. A functional diagram of the Model 4500mkII is shown in Fig. 1 wherein the Model 4500mkII consists of two main units: a transceiver 20 mounted on one side of a stack/duct 22 and a passive retroreflector 24 mounted on the other side. A light source LS in the transceiver 20 projects a beam of light 26 along the transceiver's optical axis 27 across the duct 22, through the dust/smoke in the open path 28 of the gas/smoke 29 (Fig. 2) to the retroreflector 24 which returns a reflected light beam 30 to an analyzer A in the transceiver 20. The analyzer A then compares the intensity of the returned radiation with that measured under clear-stack conditions in order to calculate the opacity and then displays this opacity value at a remote location (e.g., a data recorder, not shown). Also see U.S. Patent No. 5,617,212 (Stuart), whose entire disclosure is incorporated by reference herein, for a detailed description of how the analyzer A calculates the opacity.

Fig. 2 shows the Model 4500mkII mounted to the stack/duct 22 and depicts the internals of the transceiver 20. In particular, the light source LS of the transceiver 20 comprises an LED (light emitting diode) 32. The transceiver 20 also comprises a beamsplitter 34, a collimating lens 36, a folding mirror 38, and the analyzer A which comprises a measurement detector 40, a reference detector 42 and a processor 43 (e.g., Hitachi H8/500 microprocessor). Additional components include a flood LED 44 for drift correction, an automatic zero 46 and span 48 devices and a fail-safe shutter 50. It should be understood that the transmissometer is autocollimated meaning that the return light 30 from the retroreflector 24 is along the same path as the projected beam 26. External electrical power (e.g., 110VAC @ 60Hz), not shown, is provided to the transceiver 20 for energizing the electrical components.

The divergence 52 of the projected light beam 26 means that the retroreflector 24 returns only a portion of the projected light 26. Any change in alignment, (e.g., because of temperature changes, wind, settling, etc.) in the stack/duct 22 walls, results in a different portion of the projected beam 26 falling on the retroreflector 24. Moreover, because the projected beam 26 is not perfectly homogeneous, i.e., the light intensity varies across the projected beam (see line 54), a change in alignment results in a change in light intensity. This change is wrongly interpreted by the analyzer A as a change in the opacity of the stack/duct 22 gases.

Errors are also introduced where an opacity monitor (transmissometer) with an inhomogeneous light beam is calibrated in the laboratory and then installed on the stack/duct 22. In this case, failure to perfectly reproduce the device's optical alignment between the laboratory and the duct results in a signal offset. This offset is, in many cases,

the dominant source of error in the measurement. As a consequence, the detection limit of the opacity monitor may be set by this offset.

A number of factors affect the homogeneity of the projected beam 26, including the precision and cleanliness of the optical components used. However, the principal factor is usually the inhomogeneity of the light source LS. There are a number of factors which make the pattern of light from an LED inhomogeneous. Some of these are symmetrical about the optical axis of the LED and some are not. This is especially so when a LED source is used, since the electrical contact to the center of the die results in a dark spot in the middle of the beam 26.

One way of producing a homogeneous light source is to use an integrating sphere, such as that described in "A Guide to Integrating Sphere Theory and Applications" by Labsphere. However, an integrating sphere is both bulkier and more expensive than the present invention.

The limitations of the present state of the art are reflected in ASTM (American Society for Testing and Materials) Standard Practice for Opacity Monitor Manufacturers to Certify Conformance with Design and Performance Specifications D6216-98 (1998) which is incorporated by reference into U.S. 40 C.F.R. §60, Appendix B, EPA Performance Specification 1, and which concerns the use of opacity monitors for regulatory applications at opacity levels of 10% or higher. However, where detecting opacity levels of less than 10% is important, e.g., in the steel industry, no performance specification currently exists for the use of opacity monitors to ensure compliance with opacity limits below 10%.

Thus, there remains a need for a transmissometer that can minimize the inhomogeneity of the light source and can therefore detect opacity levels below 10% while operating within specific performance requirements.

SUMMARY OF THE INVENTION

A light source for use in an opacity monitor for measuring the opacity of gases in an open path of gases wherein the light source reduces the variation in light intensity across a beam of light projected therefrom.

A light source adapted for use in open path gas monitoring wherein the light source generates a homogeneous light beam.

An opacity monitor for measuring the opacity of gases in an open path of gases wherein opacity is defined as the fraction of transmitted light which is lost in transmission through the open path of gases. The opacity monitor comprises: an optical transmitter for projecting a light beam across the open path of gases using a light source that reduces the variation in light intensity across the projected beam; a reflector for reflecting a portion of the projected light beam back towards the optical transmitter through the open path gas of gases; an analyzer for detecting the portion of the projected light beam and calculating the opacity of the gases; and wherein the optical monitor detects opacities less than 10 percent while operating within specific performance requirements (e.g., all the requirements of ASTM D6216-98, including amendments to specific portions of ASTM D6216-98 to ensure compliance with opacity limits below 10%, such as thermal stability, insensitivity to ambient light, zero and span calibration, measurement of output resolution, calibration error, optical alignment indicator, calibration device value and repeatability, and insensitivity to supply voltage variations).

An opacity monitor for measuring the opacity of gases in an open path of gases wherein opacity is defined as the fraction of transmitted light which is lost in transmission through the open path of gases. The opacity monitor comprises: an optical transmitter having a light source that projects a homogeneous light beam across the open path of gases; a reflector for reflecting a portion of the projected homogeneous light beam back towards the optical transmitter through the open path gas of gases; an analyzer for detecting the portion of the projected homogeneous light beam and calculating the opacity of the gases; and wherein the optical monitor detects opacities less than 10 percent while operating within specific performance requirements(e.g., all the requirements of ASTM D6216-98, including amendments to specific portions of ASTM D6216-98 to ensure compliance with opacity limits below 10%, such as thermal stability, insensitivity to ambient light, zero and span calibration, measurement of output resolution, calibration error, optical alignment indicator, calibration device value and repeatability, and insensitivity to supply voltage variations).

A method for reducing the variation in light intensity across a beam of light projected from a light source used in an opacity monitor. The method comprises the steps of: (a) providing a plurality of light emitting diodes (LEDs), each having a respective optical axis and each emitting respective light beams; (b) arranging the plurality of LEDs at a predetermined angular orientation with respect to each other and aligning each of the optical axes to be parallel to each other; and (c) positioning an optical diffuser at a predetermined distance away from the plurality of LEDs for mixing and reflecting the respective light beams to form the beam of light having a reduced variation in light intensity.

A method for reducing the variation in light intensity across a beam of light projected from a light source used in an opacity monitor. The method comprises the steps of: (a) providing a plurality of light emitting diodes (LEDs), each having a respective optical axis and each having symmetrical and asymmetrical inhomogeneities in respective light beams emanating from each LED; (b) minimizing the symmetrical and asymmetrical inhomogeneities in the respective light beams by: (1) orienting the plurality of LEDs within in a common plane; and (2) positioning an optical diffuser at a predetermined distance away from the plurality of LEDs to mix and reflect the respective light beams to form the beam of light having the reduced variation in light intensity across the beam of light.

A method for measuring the opacity of gases in an open path of gases wherein opacity is defined as the fraction of transmitted light which is lost in transmission through the open path of gases. The method comprises the steps of: (a) projecting a light beam across the open path of gases using a light source that reduces the variation in light intensity across the projected beam; (b) reflecting a portion of the projected light beam; (c) detecting and analyzing the portion of the portion of the projected light beam; (d) detecting opacities less than 10 percent while operating within specific performance requirements (e.g., all the requirements of ASTM D6216-98, including amendments to specific portions of ASTM D6216-98 to ensure compliance with opacity limits below 10%, such as thermal stability, insensitivity to ambient light, zero and span calibration, measurement of output resolution, calibration error, optical alignment indicator, calibration device value and repeatability, and insensitivity to supply voltage variations).

DESCRIPTION OF THE DRAWINGS

Fig. 1 is a functional diagram of a prior art transmissometer coupled to a stack;

Fig. 2 is a side view, shown in partial cross-section, of the prior art transmissometer of Fig. 1;

Fig. 3 is an isometric view of the light source of the present invention;

Fig. 4 is an exploded view of the light source of Fig. 3;

Fig. 5 is side cross-sectional view of the light source taken along line 5-5 of Fig. 3;

Fig. 6 is a view of the light-emitting diode holder taken along line 6-6 of Fig. 5;

Fig. 7 is an exploded view showing how the light-emitting diodes are properly oriented by lead holes in a clamp plate; and

Fig. 8 is a graphical depiction of the light intensity vs. distance from the optical axis of different light emitting diodes and of the light source of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now in detail to the various figures of the drawing wherein like reference characters refer to like parts, there is shown at 100 in Fig. 3, a light source which provides improved light beam homogeneity compared to other light sources used in conventional stack/duct gas analyzers. The result of utilizing this improved light source 100 is a transmissometer analyzer which is more tolerant of optical misalignment than previous designs, and is therefore able to make accurate measurements at very low levels of opacity (e.g., less than 10%).

It should be understood that the light source 100 described herein, and as will be discussed in detail below, replaces the light source LS (e.g., LED 32) described earlier with respect to Figs. 1-2. However, in all other aspects, e.g., the beamsplitter 34, the collimating

lens 36, etc., of the transceiver portion 20 of the transmissometer which utilizes the present invention 100 is similar and is not discussed any further.

As shown most clearly in Fig. 4, the light source 100 basically comprises a plurality (e.g., three) of LEDs 102A-102C (e.g., NSPG320BS LED by Nichia Corp.) positioned in a precision-drilled holder 104, to ensure the LEDs' accurate location, and an optical diffuser 106 to blend the light output of the individual LEDs 102A-102C. In particular, the three LEDs 102A-102C are held in a precisely-determined angular orientation and location by the precision-drilled holder 104 and a clamping plate 108. As shown in Figs. 5-7, the precision-drilled holder 104 aligns the optical axis 103 (Fig. 5) of each LED 102A-102C so that they are parallel with the optical axis 27 of the transceiver 20 and also mounts the LEDs 102A-102C so that they are positioned 120° with respect to each other (tolerance on each angular position should be <10°); to properly orient these LEDs 102A-102C in the holder 104, a central boss 111 of the plastic clamp plate 108 is fitted over the leads 110 of the LEDs 102A-102C. Holes 107 in the central boss 111 fit tightly to the leads 110 ensuring the each LED 102A-102C is held in the correct angular position around its optical axis 103, with the respective flat sides 117A-117C of collars 115A-115C towards the main optical axis 27. Indicators 109 on the face of the boss 111 ensure that, during assembly, the two leads 110 of any one LED 102A-102C are inserted between two of the indicators 109 for proper LED orientation.

As mentioned earlier, there are symmetrical and asymmetrical inhomogeneities that make the pattern of light from an LED uneven. Symmetrical inhomogeneities in the light emitted by each LED 102A-102C are minimized by ensuring that the LEDs 102A-102C point straight forward, are distributed evenly across the diffuser 106, and placed at the

correct distance from it (e.g., 12.5 mm from the front of the LED flange 141 to the inside face 143 of the diffuser 106; Fig. 5). Asymmetrical unevenness (e.g., light beam asymmetry that exists due to the position of the die within each LED package as well as the chip die lead) is minimized by placing each LED 102A-102C at 120° rotation to its neighbor.

The optical (glass) diffuser 106 is mounted in a diffuser holder 122. The inside surface 124 of the holder 122 is polished to so as to reflect any scattered light. The glass diffuser 106 and the polished inside surface 122 together diffuse (e.g., reflect and mix the combined light several times) the light from the three LEDs 102A-102C to form an even, homogeneous, non-directional light source. The finish of the precision-drilled holder 104 and the internal surfaces of the diffuser holder 122 are left as "fine machined" as this provides an increased light output compared to anodizing. A glare shield 128 reduces the amount of scattered light reaching the optical detector (similar to the one shown in Fig. 2) in the transceiver 20. An aperture 126 (Fig. 5) in the glare shield 128 defines the size of the light source 100. The diffuser holder 122 is made from a low-magnesium aluminum alloy which has a low rate of oxidation and the diffuser holder 122 is sealed with silicone rubber during assembly, to prevent the ingress of any gases and therefore maintain the internal surface finish.

Electrical contacts of the LEDs 102A-102C are made by soldering the leads 110 (Fig. 4) of the LEDs 102A-102C to a printed circuit board (PCB)120. An electrical connector 130 (e.g., a 3-pin Molex connector) couples to an electrical 3-way cable (not shown) that provides electrical power to the light source 100 and a DC/DC (PCB mount) converter 131 (e.g., NME1215S by Newport) is also provided to generate the proper LED excitation.

Capacitors C1 and C2 (e.g., 10 µF, 35V, 20%, tap series) smooth out any remaining ripple from the DC/DC converter 131; the resistors R1 (Fig. 4), R4 and R5 (all zero ohms) are links which are normally set to connect the three LEDs 102A-102C in series with the option to connect them in parallel. Three screws 132A-132C (e.g., M3 x 14 STL. slot pan/hd) are used to releasably secure the various components to the PCB 120. Retainers 133 and 135 retain mounting screws 137 and 139, respectively, until the light source 100 is ready for installation in the transceiver 20 at which time the retainers 133/135 are discarded.

As mentioned earlier, the transmissometer projects a beam of light 26 across the stack/duct 22. This beam diverges slightly so that its diameter at the plane of the retro-reflector is larger than the reflecting surface. Small movements of the stack/duct 22 structure due to thermal effects, wind, or settling, cause the relative positions of the reflector and the projected beam to move slightly. If the beam does not have precisely the same intensity at all points, there will be a consequent change in the amount of light received at the detector. This will be misinterpreted as a change in the opacity of the gases in the duct.

Fig. 7 shows the variation in light intensity across a single diameter of an opal diffuser placed in front of a conventional LED light source. The box 200 represents a mask placed in front of the opal diffuser screen. Only the portion of the projected light beam between lines 200A and 200B is projected, with the rest being masked off. Lines 202, 203 and 204 are experimental measurements obtained from three different LEDs. Large variations of light intensity are apparent with respect to the distance from the optical axis. In contrast, line 205 shows the effect of placing three LEDs in the angular orientation

described above. A dramatic reduction in the variation of intensity across the projected light beam is immediately apparent.

The very small variation in light intensity across the projected light beam results in a consequent small variation of opacity due to misalignment of the transmissometer and retro-reflector. As this is a major component of the total uncertainty of the displayed opacity value, the accuracy of the transmissometer is greatly improved without any reduction in the degree of misalignment which can be tolerated.

Utilizing this improved light source 100 in an opacity monitor results in the following:

-enabling the opacity monitors to ensure compliance with opacity limits below 10% as exemplified by 40 C.F.R. §60 Paragraph 650.272 (a) (21) which requires operators of electric arc furnaces to maintain flue gas opacity at or below 3%;

-an opacity monitor that can tolerate small movements of the stack/duct structure due to thermal effects, wind, settling, etc. that can cause the relative positions of the retroreflector and the projected light beam to move slightly;

- a more evenly illuminated light source, which greatly reduces errors caused by misalignment of the transceiver and retroreflector so that stable, accurate readings can be made at opacity levels below 10%.

-a significantly brighter light source which leads to an improvement in the signal-to-noise ratio of the transmissometer.

-light source performance is highly repeatable from one opacity monitor to another.

Therefore, as a result of using the light source 100 in the transceiver 20, an opacity monitor is provided that meets what is hereinafter referred to as "specific performance requirements (SPRs)" for ensuring compliance with opacity limits below 10%. These SPRs are defined as all of the requirements of ASTM D6216-98 (a copy of which is attached as

APPENDIX) except that the indicated sections of ASTM D6216-98, set forth below, have been amended to include the following changes:

6.4 Insensitivity to Supply Voltage Variations

Permissible drift: a change of less than or equal to 0.2 percent opacity when the main supply voltage is increased or decreased from the nominal voltage by 10 percent.

6.5 Thermal Stability

Permissible drift: a change of less than or equal to 0.2 percent opacity for a 40°F (22°C) change in ambient temperature.

6.6 Insensitivity to Ambient light

Permissible drift: a change of less than or equal to 0.2 percent opacity when exposed to ambient sunlight over the course of a day.

6.8 Zero and Span Calibration

Zero error: 0.2% or less

6.12 Measurement Output Resolution

Resolution of visual indication: 0.1%
Resolution of analog output: 0.1%
Resolution of digital output: 0.1%

7.8 Calibration Error

$\leq$1 % opacity

7.9 Optical Alignment Indicator

Opacity monitor, when misaligned, displays a clear indication of that misaligment if the resulting change in opacity is 0.3% or greater.

7.11 Calibration Device Value and Repeatability

Repeatability: 0.2% or less
95% confidence limit: 0.3%

Without further elaboration, the foregoing will so fully illustrate our invention that others may, by applying current or future knowledge, readily adopt the same for use under various conditions of service.

Designation: D 6216 – 98

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428

Standard Practice for Opacity Monitor Manufacturers to Certify Conformance with Design and Performance Specifications[1]

This standard is issued under the fixed designation D 6216; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the procedure for certifying continuous opacity monitors. It includes design and performance specifications, test procedures, and quality assurance requirements to ensure that continuous opacity monitors meet minimum design and calibration requirements, necessary in part, for accurate opacity monitoring measurements in regulatory environmental opacity monitoring applications subject to 10 % or higher opacity standards.

1.2 This practice applies specifically to the original manufacturer, or to those involved in the repair, remanufacture, or resale of opacity monitors.

1.3 Test procedures that specifically apply to the various equipment configurations of component equipment that comprise either a transmissometer, an opacity monitor, or complete opacity monitoring system are detailed in this practice.

1.4 The specifications and test procedures contained in this practice exceed that of the United States Environmental Protection Agency (USEPA). For each opacity monitor or monitoring system that the manufacturer demonstrates conformance to this practice, the manufacturer may issue a certificate that states that that opacity monitor or monitoring system conforms with all of the applicable design and performance requirements of 40 CFR 60, Appendix B, Performance Specification 1 except those for which tests are required after installation.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[2]

2.2 *U.S. Environmental Protection Agency Document:*[3]

40 CFR 60 Appendix B, Performance Specification 1

2.3 *Other Documents:*

ISO/DIS 9004 Quality Management and Quality System Elements-Guidelines[4]

ANSI/NCSL Z 540-1-1994 Calibration Laboratories and Measuring Equipment - General Requirements[4]

NIST 260-116 - Filter calibration procedures[5]

3. Terminology

3.1 For terminology relevant to this practice, see Terminology D 1356.

3.2 *Definitions of Terms Specific to This Standard:*

Analyzer Equipment

3.2.1 *opacity, n*—measurement of the degree to which particulate emissions reduce (due to absorption, reflection, and scattering) the intensity of transmitted photopic light and obscure the view of an object through ambient air, an effluent gas stream, or an optical medium, of a given pathlength.

3.2.1.1 *Discussion*—Opacity (Op), expressed as a percent, is related to transmitted light, (T) through the equation:

$$Op = (1 - T)(100). \tag{1}$$

3.2.2 *opacity monitor, n*—an instrument that continuously determines the opacity of emissions released to the atmosphere.

3.2.2.1 *Discussion*—An opacity monitor includes a transmissometer that determines the *in-situ* opacity, a means to correct opacity measurements to equivalent single-pass opacity values that would be observed at the pathlength of the emission outlet, and all other interface and peripheral equipment necessary for continuous operation.

3.2.2.2 *Discussion*—An opacity monitor may include the following: (*1*) sample interface equipment such as filters and purge air blowers to protect the instrument and minimize contamination of exposed optical surfaces, (*2*) shutters or other devices to provide protection during power outages or failure of the sample interface, and (*3*) a remote control unit to facilitate monitoring the output of the instrument, initiation of zero and upscale calibration checks, or control of other capacity monitor functions.

3.2.3 *opacity monitor model, n*—a specific transmissometer or opacity monitor configuration identified by the specific

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[1] This practice is under the jurisdiction of ASTM Committee D-22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.03 on Ambient Atmospheres and Source Emissions.

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[2] *Annual Book of ASTM Standards*, Vol 11.03.

[3] Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

[4] Available from American National Standards Institute, 11 W. 42nd St., 13th floor, New York, NY 10036.

[5] Available from National Institute of Standards and Technology, Gaithersburg, MD 20899.

measurement system design, including: (*1*) the use of specific light source, detector(s), lenses, mirrors, and other optical components, (*2*) the physical arrangement of optical and other principal components, (*3*) the specific electronics configuration and signal processing approach, (*4*) the specific calibration check mechanisms and drift/dust compensation devices and approaches, and (*5*) the specific software version and data processing algorithms, as implemented in a particular manufacturing process, at a particular facility and subject to an identifiable quality assurance system.

3.2.3.1 *Discussion*—Changing the retro-reflector material or the size of the retro-reflector aperture is not considered to be a model change unless it changes the basic attributes of the optical system.

3.2.4 *opacity monitoring system, n*—the entire set of equipment necessary to monitor continuously the in-stack opacity, average the emission measurement data, and permanently record monitoring results.

3.2.4.1 *Discussion*—An opacity monitoring system includes at least one opacity monitor with all of its associated interface and peripheral equipment and the specific data recording system (including software) employed by the end user. An opacity monitoring system may include multiple opacity monitors and a common data acquisition and recording system.

3.2.5 *optical density (OD), n*—a logarithmic measure of the amount of incident light attenuated.

3.2.5.1 *Discussion*—OD is related to transmittance and opacity as follows:

$$OD = \log_{10} (1/T) = -\log_{10} (T) = -\log_{10} (1-Op), \quad (2)$$

where Op is expressed as a fraction.

3.2.6 *transmittance, n*—the fraction of incident light within a specified optical region that passes through an optical medium.

3.2.7 *transmissometer, n*—an instrument that passes light through a particulate-laden effluent stream and measures *in situ* the optical transmittance of that light within a specified wavelength region.

3.2.7.1 *Discussion*—Single-pass transmissometers consist of a light source and detector components mounted on opposite ends of the measurement path. Double-pass instruments consist of a transceiver (including both light source and detector components) and a reflector mounted on opposite ends of the measurement path.

3.2.7.2 *Discussion*—For the purposes of this practice, the transmissometer includes the following mechanisms (1) means to verify the optical alignment of the components and (2) simulated zero and upscale calibration devices to check calibration drifts when the instrument is installed on a stack or duct.

3.2.7.3 *Discussion*—Transmissometers are sometimes referred to as *opacity analyzers* when they are configured to measure opacity.

Analyzer Zero Adjustments and Devices

3.2.8 *dust compensation, n*—a method or procedure for systematically adjusting the output of a transmissometer to account for reduction in transmitted light reaching the detector (apparent increase in opacity) that is specifically due to the accumulation of dust (that is, particulate matter) on the exposed optical surfaces of the transmissometer.

3.2.8.1 *Discussion*—The dust compensation is determined relative to the previous occasion when the exposed optics were cleaned and the dust compensation was reset to zero. The determination of dust accumulation on surfaces exposed to the effluent must be limited to only those surfaces through which the light beam passes under normal opacity measurement and the simulated zero device or equivalent mechanism necessary for the dust compensation measurement.

3.2.8.2 *Discussion*—The dust accumulation for all of the optical surfaces included in the dust compensation method must actually be measured. Unlike zero drift, which may be either positive or negative, dust compensation can only reduce the apparent opacity. A dust compensation procedure can correct for specific bias and provide measurement results equivalent to the *clean window* condition.

3.2.8.3 *Discussion*—The opacity monitor must provide a means to display the level of dust compensation. Regulatory requirements may impose a limit on the amount of dust compensation that can be applied and require that an alarm be activated when the limit is reached.

3.2.9 *external zero device, n*—an external device for checking the zero alignment of the transmissometer by simulating the zero opacity condition for a specific installed opacity monitor.

3.2.10 *simulated zero device, n*—an automated mechanism within the transmissometer that produces a simulated clear path condition or low level opacity condition.

3.2.10.1 *Discussion*—The simulated zero device is used to check zero drift daily or more frequently and whenever necessary (for example, after corrective actions or repairs) to assess opacity monitor performance while the instrument is installed on the stack or duct.

3.2.10.2 *Discussion*—The proper response to the simulated zero device is established under clear path conditions while the transmissometer is optically aligned at the installation pathlength and accurately calibrated. The simulated zero device is then the surrogate, clear path calibration value, while the opacity monitor is in service.

3.2.10.3 *Discussion*—Simulated zero checks do not necessarily assess the optical alignment, the reflector status (for double-pass systems), or the dust contamination level on all optical surfaces. (See also 6.9.1.)

3.2.11 *zero alignment, n*—the process of establishing the quantitative relationship between the simulated zero device and the actual clear path opacity responses of a transmissometer.

3.2.12 *zero compensation, n*—an automatic adjustment of the transmissometer to achieve the correct response to the simulated zero device.

3.2.12.1 *Discussion*—The zero compensation adjustment is fundamental to the transmissometer design and may be inherent to its operation (for example, continuous adjustment based on comparison to reference values/conditions, use of automatic control mechanisms, rapid comparisons with simulated zero and upscale calibration drift check values, and so forth) or it may occur each time a calibration check cycle (zero and upscale calibration drift check) is performed by

applying either analog or digital adjustments within the transmissometer.

3.2.12.2 *Discussion*—For opacity monitors that do not distinguish between zero compensation and dust compensation, the accumulated zero compensation may be designated as the dust compensation. Regulatory requirements may impose a limit on the amount of dust compensation that can be applied and require that an alarm be activated when the limit is reached.

3.2.13 *zero drift, n*—the difference between the opacity monitor response to the simulated zero device and its nominal value (reported as percent opacity) after a period of normal continuous operation during which no maintenance, repairs, or external adjustments to the opacity monitor took place.

3.2.13.1 *Discussion*—Zero drift may occur due to changes in the light source, changes in the detector, variations due to internal scattering, changes in electronic components, or varying environmental conditions such as temperature, voltage or other external factors. Depending on the design of the transmissometer, particulate matter (that is, dust) deposited on optical surfaces may contribute to zero drift. Zero drift may be positive or negative.

Calibrations and Adjustments

3.2.14 *attenuator, n*—a glass or grid filter that reduces the transmittance of light.

3.2.15 *calibration drift, n*—the difference between the opacity monitor response to the upscale calibration device and its nominal value after a period of normal continuous operation during which no maintenance, repairs, or external adjustments to the opacity monitor took place.

3.2.15.1 *Discussion*—Calibration drift may be determined after determining and correcting for zero drift. For opacity monitors that include automatic zero compensation or dust compensation features, calibration drift may be determined after zero drift or dust compensation, or both, are applied.

3.2.16 *calibration error, n*—the sum of the absolute value of the mean difference and confidence coefficient for the opacity values indicated by an optically aligned opacity monitor (laboratory test) or opacity monitoring system (field test) as compared to the known values of three calibration attenuators under clear path conditions.

3.2.16.1 *Discussion*—The calibration error indicates the fundamental calibration status of the opacity.

3.2.17 *external adjustment, n*—either (*1*) a physical adjustment to a component of the opacity monitoring system that affects its response or its performance, or (*2*) an adjustment applied by the data acquisition system (for example, mathematical adjustment to compensate for drift) which is external to the transmissometer and control unit, if applicable.

3.2.17.1 *Discussion*—External adjustments are made at the election of the end user but may be subject to various regulatory requirements.

3.2.18 *intrinsic adjustment, n*—an automatic and essential feature of an opacity monitor that provides for the internal control of specific components or adjustment of the opacity monitor response in a manner consistent with the manufacturer's design of the instrument and its intended operation.

3.2.18.1 *Discussion*—Examples of intrinsic adjustments include automatic gain control used to maintain signal amplitudes constant with respect to some reference value, or the technique of ratioing the measurement and reference beams in dual beam systems. Intrinsic adjustments are either non-elective or are configured according to factory recommended procedures; they are not subject to change from time to time at the discretion of the end user.

3.2.19 *upscale calibration device, n*—an automated mechanism (employing a filter or reduced reflectance device) within the transmissometer that produces an upscale opacity value.

3.2.19.1 *Discussion*—The upscale calibration device is used to check the upscale drift of the measurement system. It may be used in conjunction with the simulated zero device (for example, filter superimposed on simulated zero reflector) or a parallel fashion (for example, zero and upscale (reduced reflectance) devices applied to the light beam sequentially). (See also 6.9.2.)

Opacity Monitor Location Characteristics

3.2.20 *installation pathlength, n*—the installation flange-to-flange separation distance between the transceiver and reflector for a double-pass transmissometer or between the transmitter and receiver for a single-pass transmissometer.

3.2.21 *monitoring pathlength, n*—the effective single pass depth of effluent between the receiver and the transmitter of a single-pass transmissometer, or between the transceiver and reflector of a double-pass transmissometer at the installation location.

3.2.22 *emission outlet pathlength, n*—the physical pathlength (single pass depth of effluent) at the location where emissions are released to the atmosphere.

3.2.22.1 *Discussion*—For circular stacks, the emission outlet pathlength is the internal diameter at the stack exit. For non-circular outlets, the emission outlet pathlength is the hydraulic diameter. For rectangular stacks:

$$D = (2LW)/(L + W), \tag{3}$$

where L is the length of the outlet and W is the width of the stack exit.

3.2.23 *pathlength correction factor (PLCF), n*—the ratio of the emission outlet pathlength to the monitoring pathlength.

3.2.23.1 *Discussion*—The PLCF is used to calculate the equivalent single pass opacity that would be observed at the stack exit.

3.2.23.2 *Discussion*—A number of similar terms are found in the literature, manufacturer operating manuals, and in common usage. OPLR (optical pathlength ratio) and STR (stack taper ratio) are common. The OPLR is equal to one half of the pathlength correction. Refer to the instrument manufacturer for the proper factor.

Opacity Monitor Optical Characteristics

3.2.24 *angle of projection (AOP), n*—the total angle that contains all of the visible (photopic) radiation projected from the light source of the transmissometer at a level greater than 2.5 % of its peak illuminance.

3.2.25 *angle of view (AOV), n*—the total angle that contains all of the visible (photopic) radiation detected by the

photodetector assembly of the transmissometer at a level greater than 2.5 % of the peak detector response.

3.2.26 *instrument response time, n*—the time required for the electrical output of an opacity monitor to achieve 95 % of a step change in the path opacity.

3.2.27 *mean spectral response, n*—the mean response wavelength of the wavelength distribution for the effective spectral response curve of the transmissometer.

3.2.28 *optical alignment indicator, n*—a device or means to determine objectively the optical alignment status of opacity monitor components.

3.2.29 *peak spectral response, n*—the wavelength of maximum sensitivity of the transmissometer.

3.2.30 *photopic, n*—a region of the electromagnetic spectrum defined by the response of the light-adapted human eye as characterized in the "Source C, Human Eye Response" contained in 40CFR60, Appendix B, Performance Specification 1.

4. Summary of Practice

4.1 A comprehensive series of specifications and test procedures that opacity monitor manufacturers must use to certify opacity monitoring equipment (that is, that the equipment meets minimum design and performance requirements) prior to shipment to the end user is provided. The design and performance specifications are summarized in Table 1.

4.2 Design specifications and test procedures for (*1*) peak and mean spectral responses, (*2*) angle of view and angle of projection, (*3*) insensitivity to supply voltage variations, (*4*) thermal stability, (*5*) insensitivity to ambient light, and (*6*) an optional procedure for opacity monitors with external zero devices that states or other regulatory agencies might require are included. The manufacturer periodically selects and tests for conformance with these design specifications an instrument that is representative of a group of instruments) produced during a specified period or lot. Non-conformance with the design specifications requires corrective action and retesting. Each remanufactured opacity monitor must be tested to demonstrate conformance with the design specifications. The test frequency, transmissometer installation pathlength (that is, set-up distance) and pathlength correction factor for each design specification test are summarized in Table 2.

4.3 This practice includes manufacturer's performance specifications and test procedures for (*1*) instrument response time, (*2*) calibration error, (*3*) optical alignment sight performance - homogeneity of light beam and detector. It also includes a performance check of the spectral response of the instrument. Conformance with these performance specifications is determined by testing each opacity monitor prior to shipment to the end user. (The validity of the results of the calibration error test depends upon the accuracy of the installation pathlength measurements, which is provided by the end user.) The test frequency, transmissometer installation pathlength (that is, set-up distance) and pathlength correction factor for each performance specification test are summarized in Table 3.

4.4 This practice establishes appropriate guidelines for QA programs for manufacturers of continuous opacity monitors, including corrective actions when non-conformance with specifications is detected.

TABLE 1 Summary of Manufacturer's Specifications and Requirements

Specification	Requirement
Spectral response	peak and mean spectral response between 500 and 600 nm: less than 10% of peak response below 400 nm and above 700 nm
Angle of view, angle of projection	≤4° for all radiation above 2.5 % of peak
Insensitivity to supply voltage variations	±1.0 % opacity max. change over specified range of supply voltage variation, or ±10 % variation from the nominal supply voltage
Thermal stability	±2.0 % opacity change per 40°F change over specified operational range
Insensitivity to ambient light	±2.0 % opacity max. change from sunrise to sunset with at least one 1-h average solar radiation level of ≥ 900 W/m²
External audit filter access	required
External zero device repeatability - Optional	±1.0 % opacity
Automated calibration checks	check of all active analyzer internal optics with power or curvature, all active electronic circuitry including the light source and photodetector assembly, and electric or electro-mechanical systems used during normal measurement operation
Simulated zero check device	simulated condition during which the energy reaching the detector is between 90 and 190 % of the energy reaching the detector under actual clear path conditions
Upscale calibration check device	check of the measurement system where the energy level reaching the detector is between the energy levels corresponding to 10 % opacity and the highest level filter used to determine calibration error
Status indicators	manufacturer to identify and specify
Pathlength correction factor security	manufacturer to specify one of three options
Measurement output resolution	0.5 % opacity over measurement range from -5 % to 50 % opacity, or higher value
Measurement and recording frequency	sampling and analyzing at least every 10 s: calculate averages from at least 6 measurements per minute
Instrument response time	≤10 s to 95 % of final value
Calibration error	≤3 % opacity for the sum of the absolute value of mean difference and 95 % confidence coefficient for each of three test filters
Optical alignment indicator - (uniformity of light beam and detector)	clear indication of misalignment at or before the point where opacity changes ±2 % due to misalignment as system is misaligned both linearly and rotationally in horizontal and vertical planes
Calibration device repeatability	≤1.5 % opacity

5. Significance and Use

5.1 Continuous opacity monitors are required to be installed at many stationary sources of air pollution by federal, state, and local air pollution control agency regulations. EPA regulations

TABLE 2 Manufacturer's Design Specifications – Test Frequency, Set-Up Distance, and Pathlength Correction Factor

Manufacturer's Design Specification	Test Frequency	Set-Up Distance	Pathlength Correction Factor
Spectral Response	annually, and following failure of spectral response performance check[A]	1 to 3 m when measured (not applicable when spectral response is calculated)	NA
Angle of view, angle of projection	monthly, or 1 in 20 units (whichever is more frequent)	3 m	NA
Insensitivity to supply voltage variations	monthly, or 1 in 20 units (whichever is more frequent)	3 m	1.0
Thermal stability	annually[B]	3 m (external jig for tests)	1.0
Insensitivity to ambient light	annually[B]	3 m	1.0
External zero device repeatability - optional	annually[B]	3 m	1.0
Additional design specifications[C]	as applicable		

[A]The spectral response is determined annually for each model and whenever there is a change in the design, manufacturing process, or component that might affect performance. Reevaluation of the spectral response is necessary when an instrument fails to meet the spectral response performance check.

[B]Annually, and whenever there is a change in the design, manufacturing process, or component that might affect performance.

[C]The manufacturer shall certify that the opacity monitor design meets the applicable requirements for (*a*) external audit filter access, (*b*) external zero device (if applicable), (*c*) simulated zero and upscale calibration devices, (*d*) status indicators, (*e*) pathlength correction factor security, (*f*) measurement output resolution, and (*g*) measurement recording frequency.

TABLE 3 Manufacturer's Performance Specification – Test Applicability, Set-Up Distance and Pathlength Correction Factor

Manufacturer's Performance Specification	Test Applicability	Set-Up Distance	Pathlength Correction Factor
Instrument response time	each instrument	per actual installation	per actual installation
Calibration error	each instrument	per actual installation[A]	per actual installation[A]
Acceptable tolerance comparing test to actual conditions		±10 % reset clear path zero values for subsequent monitoring[B]	±10 %, use actual value for all subsequent monitoring[B]
Optical alignment indicator - (uniformity of light beam and detector)	each instrument	per actual installation	per actual installation
Spectral response performance check	each instrument	per actual installation	per actual installation
Calibration device repeatability	each instrument	per actual installation	per actual installation

[A] Default test values are provided for use where the installation pathlength and pathlength correction factor can not be determined.

[B]When actual measurements are within ±10 % tolerance, a field performance audit can be performed rather than a field calibration error test at the time of installation.

regarding the design and performance of opacity monitoring systems for sources subject to "Standards of Performance for New Stationary Sources" are found in 40 CFR 60, Subpart A General Provisions, §60.13 Monitoring Provisions, Appendix B, Performance Specification 1, and in applicable source-specific subparts. Many states have adopted these or very similar requirements for opacity monitoring systems.

5.2 Regulated industrial facilities are required to report continuous opacity monitoring data to control agencies on a periodic basis. The control agencies use the data as an indirect measure of particulate emission levels and as an indicator of the adequacy of process and control equipment operation and maintenance practices.

5.3 EPA Performance Specification 1 provides minimum specifications for opacity monitors and requires source owners or operators of regulated facilities to demonstrate that their installed systems meet certain design and performance specifications. Performance Specification 1 allows, as an alternative to testing each instrument, manufacturers to demonstrate conformance with certain design specifications by selecting and testing representative instruments.

5.4 Previous experience has demonstrated that EPA Performance Specification 1 does not address all of the important design and performance parameters for opacity monitoring systems. The additional design and performance specifications included in this practice are needed to eliminate many of the performance problems that have been encountered. This practice also provides purchasers and vendors flexibility, by designing the test procedures for basic transmissometer components or opacity monitors, or in certain cases, complete opacity monitoring systems. However, the specifications and test procedures are also sufficiently detailed to support the manufacturer's certification and to facilitate independent third party evaluations (if desired) of the procedures.

5.5 Purchasers of opacity monitoring equipment meeting all of the requirements of this practice are assured that the opacity monitoring equipment meets all of the design requirements of EPA Performance Specification 1, and additional design specifications that eliminate many of the operational problems that have been encountered in the field. Purchasers can rely on the manufacturer's published operating range specifications for ambient temperature and supply voltage. These purchasers are also assured that the specific instrument has been tested at the point of manufacture and demonstrated to meet the manufacturer's performance specifications for instrument response time, calibration error (based on pathlength measurements provided by the end user), optical alignment, and the spectral response performance check requirement. Conformance with the requirements of this practice ensures conformance with all of the requirements of 40CFR60, Appendix B, Performance Specification 1 except those requirements for which tests are required after installation.

5.6 The original manufacturer, or those involved in the repair, remanufacture, or resale of opacity monitors can use this practice to demonstrate that the equipment components or opacity monitoring systems provided meet appropriate design and performance specifications.

5.7 The applicable test procedures and specifications of this practice are selected to address the equipment and activities that are within the control of the manufacturer; they do not mandate testing of the opacity system data recording equipment or reporting.

5.8 This practice also may serve as the basis for third party independent audits of the certification procedures used by manufacturers of opacity monitoring equipment.

6. Procedure—Design Specification Verification

6.1 *Test Opacity Monitor Selection, Test Frequency, and Summary of Tests*:

6.1.1 Perform the design specification verification procedures in this section for each representative model or configuration involving substantially different optics, electronics, or software before being shipped to the end user.

6.1.2 At a minimum, select one opacity monitor from each month's production, or one opacity monitor from each group of twenty opacity monitors, whichever is more frequent. Test this opacity monitor for (*1*) angle of view, (*2*) angle of projection, and (*3*) insensitivity to supply voltage variations. If any design specification is unacceptable, institute corrective action according to the established quality assurance program and remedy the cause of unacceptability for all opacity monitors produced during the month or group of twenty. In addition, test all of the opacity monitors in the group and verify conformance with the design specifications before shipment to the end users.

NOTE 1—The selected opacity monitor may be the first opacity monitor produced each month, or the first opacity monitor in each group of twenty, provided that it is representative of the entire group.

6.1.3 At a minimum, test one opacity monitor each year for (*1*) spectral response, (*2*) thermal stability, and (*3*) insensitivity to ambient light. If any design specification is unacceptable, institute corrective action according to the established quality assurance program and remedy the cause of unacceptability for all affected opacity monitors. In addition, retest another representative opacity monitor after corrective action has been implemented to verify that the problem has been resolved.

6.1.4 Certify that the opacity monitor design meets the applicable requirements (see 6.7-6.13) for (*1*) external audit filter access, (*2*) external zero device (if applicable), (*3*) simulated zero and upscale calibration devices, (*4*) status indicators, (*5*) pathlength correction factor security, (*6*) measurement output resolution, and (*7*) measurement recording frequency. Maintain documentation of tests and data necessary to support certification.

6.2 *Spectral Response*:

NOTE 2—The purpose of the spectral response specifications is to ensure that the transmissometer measures the transmittance of light within the photopic range. The spectral response requirements ensure some level of consistency among opacity monitors because the determination of transmittance for effluent streams depends on the particle size, wavelength, and other parameters. The spectral response requirements also eliminate potential interfering effects due to absorption by various gaseous constituents except NO_2 which can be an interferent if present in abnormally high concentrations or over long pathlengths, or both. The spectral response requirements apply to the entire transmissometer. Any combination of components may be used in the transmissometer so long as the response of the entire transmissometer satisfies the applicable requirements.

6.2.1 *Test Frequency*— See 6.1.3. In addition, conduct this test (*1*) anytime a change in the manufacturing process occurs or a change in a component that may affect the spectral response of the transmissometer occurs or (*2*) on each opacity monitor that fails the spectral response performance check in 7.10.

6.2.2 *Specification*— The peak and mean spectral responses must occur between 500 nm and 600 nm. The response at any wavelength below 400 nm and above 700 nm must be less than 10 % of the peak spectral response. Calculate the mean spectral response as the arithmetic mean value of the wavelength distribution for the effective spectral response curve of the transmissometer.

6.2.3 *Spectral Response Design Specification Verification Procedure*—Determine the spectral response of the transmissometer by either of the procedures in 6.2.4 (Option 1) or 6.2.5 (Option 2), then calculate the mean response wavelength from the normalized spectral response curve according to 6.2.6. Option 1 is to measure the spectral response using a variable slit monochromator. Option 2 is to determine the spectral response from manufacturer-supplied data for the active optical components of the measurement system.

6.2.4 *Option 1, Monochromator*—Use the following procedure:

6.2.4.1 Verify the performance of the monochromator using a NIST traceable photopic band pass filter or light source, or both.

6.2.4.2 Set-up, optically align, and calibrate the transmissometer for operation on a pathlength of 1 to 3 m.

6.2.4.3 Connect an appropriate data recorder to the transmissometer and adjust the gain to an acceptable measurement level.

6.2.4.4 Place the monochromator in the optical path with the slit edge at an appropriate distance from the permanently mounted focusing lenses.

6.2.4.5 Use the monochromator with a range from 350 nm to 750 nm or greater resolution. Record the response of the transmissometer at each wavelength in units of optical density or voltage.

6.2.4.6 Cover the reflector for double-pass transmissometers, or turn off the light source for single-pass transmissometers, and repeat the test to compensate measurement values for dark current at each wavelength.

6.2.4.7 Determine the spectral response from the opacity monitor double pass response and the monochromator calibration.

6.2.4.8 Graph the raw spectral response of the transmissometer over the test range.

6.2.4.9 Normalize the raw response curve to unity by dividing the response at 10 nm intervals by the peak response.

6.2.5 *Option 2, Calculation from Manufacturer Supplied Data*—Obtain data from component suppliers that describes the spectral characteristics of the light source, detector, filters, and all other optical components that are part of the instrument design and affect the spectral response of the transmissometer. Ensure that such information is accurately determined using reliable means and that the information is representative of the specific components used in current production of the transmissometer under evaluation. Update the information at least every year or when new components are used, or both. Keep the information and records necessary to demonstrate its applicability to the current spectral response determination on file. Using the component manufacturer-supplied data, calculate the effective spectral response for the transmissometer as follows:

6.2.5.1 Obtain the spectral emission curve for the source.

The data must be applicable for the same voltages or currents, or both, as that used to power the source in the instrument.

6.2.5.2 Obtain the spectral sensitivity curve for the detector that is being used in the system.

6.2.5.3 Obtain spectral transmittance curves for all filters and other active optical components that affect the spectral response.

6.2.5.4 Perform a point-wise multiplication of the data obtained in 6.2.5.1-6.2.5.3, at 10 nm intervals, over the range 350 to 750 nm, to yield the raw response curve for the system.

6.2.5.5 Normalize the raw response curve to unity by dividing the response at 10 nm intervals by the peak response.

6.2.6 Using the results from Option 1 or 2, as applicable, determine conformance to the specifications in 6.2.2. Then calculate the mean response wavelength (response-weighted average wavelength) by (*1*) multiplying the response at 10 nm intervals by the wavelength, (*2*) summing all the products, and (*3*) dividing by the sum of all 10 nm interval responses. Verify that this result is greater than 500 nm but less than 600 nm.

6.2.7 *Monitor-Specific Performance Check Limits*—Establish the monitor-specific performance check limits for use in conducting the Spectral Response Performance Check (7.10) as follows:

NOTE 3—The equivalent single-pass opacity from 6.2.7.2 and the single-pass opacity results corresponding to the applicable shifts from 6.2.7.3 bound the acceptable limits for the spectral response performance check.

6.2.7.1 Obtain a photopic transmission filter that has (*1*) a peak transmission ≥70 %, (*2*) maximum transmission between 550 nm and 560 nm, (*3*) half-maximum transmission between 500 nm and 520 nm, (*4*) half-maximum transmission between 600 nm and 620 nm, (*5*) transmission <10 % at any wavelength less than 450 nm or greater than 650 nm, and (*6*) a traceable calibration. Calibrate and verify the transmittance of the photopic filter as a function of wavelength initially and at least annually.

6.2.7.2 Calculate the expected single-pass opacity (assuming PLCF=1) that would result from inserting the photopic transmission filter into the clear-stack path of the transmissometer by (*1*) performing a point-wise multiplication of the photopic transmission filter curve with the normalized transmissometer response curve (obtained from 6.2.4.9 or 6.2.5.5), (*2*) summing the products, (*3*) dividing by the sum of the 10 nm responses to form the single-pass transmission, and (*4*) calculating the equivalent single-pass opacity.

6.2.7.3 Repeat the calculations in 6.2.7.2, except use (*1*) the normalized transmissometer curve shifted by +20 nm or the amount which would cause the peak or mean spectral response to shift to the limiting value of 600 nm, whichever shift is less, and (*2*) the normalized transmissometer curve shifted by –20 nm or the amount which would cause the peak or mean spectral response to shift to the limiting value of 500 nm, whichever shift is less.

6.2.7.4 Repeat the calculations with any design changes involving the source, detector(s), or light transmitting optics. Although failure of the spectral response performance check in 7.10 does not necessarily mean that the transmissometer response is no longer within the photopic range, it is a sufficient basis to warrant additional investigation, including reevaluation of the spectral response and performance check limits, explanation, and documentation of the problem.

6.3 *Angle of View and Angle of Projection*:

NOTE 4—The purpose of the angle of view (AOV) and angle of projection (AOP) design specifications is to minimize the effects of light scattering in the measurement path when determining transmittance or opacity.

6.3.1 *Test Frequency*— See 6.1.2. Manufacturers that demonstrate and document using good engineering practice that a specific design results in an AOP of less than 0.5° are not required to perform the following AOP or AOV tests.

6.3.2 *Specification*— The total AOP and the total AOV must each be no greater than 4°. Transmissometers with an AOP of less than 0.5° are exempt from the AOV or AOP specification.

6.3.3 *AOV and AOP Design Specification Verification Procedure*—Conduct the AOV and AOP tests using the procedures given in 6.3.4-6.3.13.

6.3.4 *Transmissometer Configuration*—Conduct the AOV and AOP tests with the complete transmissometer assembly, including all parts of the measurement system that may impact the results. Provide a justification of (*1*) exactly what is included and excluded from the AOV and AOP tests and (*2*) any test procedure modifications necessary to accommodate particular designs, such as those that may be required for dual beam designs that are chopped and synchronously detected. Include the justifications with documentation of the results.

6.3.5 *Set-Up*—Focus and configure the transmissometer for a flange-to-flange installation separation distance of 3 m.

6.3.6 *Test Fixture*— Set up the AOV test fixture that incorporates (*1*) a movable light source along arcs of 3 m radius relative to the first optical surface encountered by the light beam entering the detector housing assembly, in both the horizontal and vertical directions relative to the normal installation orientation, and (*2*) recording measurements at 2.5 cm increments along the arc. Similarly, set up the AOP test fixture that incorporates (*1*) a movable photodetector along an arc of 3 m radius relative to the final optical surface encountered by the light beam exiting the transmitter housing assembly, in both the horizontal and vertical directions relative to the normal installation orientation, and (*2*) recording measurements at 2.5 cm increments along the arc.

NOTE 5—It is helpful to mount on test stands the detector and transmitter housings for single-pass transmissometers, or the transceiver for double-pass transmissometers.

6.3.7 *Alternative Test Fixture*—For the AOV test, at a distance of 3 m from a stationary light source, mount the detector housing on a turntable that can be rotated (both horizontally and vertically) in increments of 0.5° [28.6 min], corresponding to measurements displaced 2.5 cm along the arc, to a maximum angle of 5° (corresponding to a distance of 26 cm along the arc) on either side of the alignment centerline. Similarly, for the AOP test, mount transmitter housing on the turntable at a distance of 3 m relative to a stationary photodetector.

NOTE 6—If the turntable is capable of rotating only in either the horizontal or vertical direction, the detector or transmitter housing may be

mounted on its side or bottom (as appropriate) to simulate the other direction.

6.3.8 *Light Source*— For the AOV test, use a small non-directional light source (less than 3 cm wide relative to the direction of movement) that (*1*) includes the visible wavelengths emitted by the light source installed in the transmissometer, (*2*) provides sufficient illuminance to conduct the test but doe snot saturate the detector, (*3*) does not include lenses or focusing devices, and (*4*) does not include non-directional characteristics, that is, the intensity in the 20° sector facing the detector assembly varies by less than ±10 %.

NOTE 7—A light source that does not meet the non-directional criteria may still be used for the AOV test, if a specific procedure is followed. This procedure is given in 6.3.9.

6.3.9 *Alternative Light Source*—For the AOV test, if the light source does not meet the non-directional criteria, rotate the light source in the vertical and horizontal planes about its normal optical axis as it is pointed at the entrance aperture of the instrument under test in order to obtain the maximum response from the instrument under test at each position in the test procedure.

6.3.10 *AOV Test Procedure*—Test the entire detector assembly (that is, transceiver for double-pass transmissometers or receiver/detector for a single-pass transmissometer). If applicable, include the mounting flanges normally supplied with the opacity monitor. Use an appropriate data recorder to record continuously the detector response during the test.

NOTE 8—Alternative AOV test procedures are necessary for certain designs. For example, a transmissometer with an optical chopper/modulator responds only to light modulated at a certain frequency. An external chopper/modulator used in conjunction with the test light source must match both the phase and duty cycle for accurate results. If this cannot be done, the manufacturer may either (*1*) provide additional electronics to drive another similar external source in parallel wit the internal source or (*2*) modify the detector electronics so that its response may be used to accurately evaluate the AOV of the test transmissometer. The manufacturer must take appropriate measures to ensure (*1*) that the background, or ambient light, and detector offsets do not significantly reduce the accuracy of the AOV measurements, (*2*) that the field of view restricting hardware normally included with the instrument are not modified in any way, and (*3*) that good engineering practice is followed in the design of the test configuration to ensure an accurate measurement of AOV.

6.3.10.1 Align the test light source at the center position and observe the detector assembly response. Optimize the test light source and optical chopper/modulator (if applicable) to maximize the detector assembly response. If the detector response is not within the normal operating range (that is, 25 to 200 % of the energy value equivalent to a clear path transmittance measurement for the transmissometer), adjust the test apparatus (for example, light source power supply) to achieve a detector response in the acceptable range.

6.3.10.2 Position the test light source on the horizontal arc 26 cm from the detector centerline (5°) and record the detector response. Move the light source along the arc at intervals not larger than 2.5 cm (or rotate the turntable in increments not larger than 0.5°) and record the detector response for each measurement location. Continue to make measurements through the aligned position and on until a position 26 cm (5°) on the opposite side of the arc from the starting position is reached. Record the response for each measurement location and over the full test range; continue recording data for all positions up to 26 cm (5°) even if no response is observed at an angle of ≤26 cm (5°) from the centerline.

6.3.10.3 Repeat the AOV test on an arc in the vertical direction relative to the normal orientation of the detector housing.

6.3.10.4 For both the horizontal and vertical directions, calculate the relative response of the detector as a function of viewing angle (response at each measurement location as a percentage of the peak response). Determine the maximum viewing angle for the horizontal and vertical directions yielding a response greater than 2.5 % of the peak response. Determine conformance to the specification in 6.3.2. Report these angles as the angle of view. Report the relative angle of view curves in both the horizontal and vertical directions. Document and explain any modifications to the test procedures as described in 6.3.11.

6.3.11 *AOP Test Procedure*—Perform this test for the entire light source assembly (that is, transceiver for double-pass transmissometers or transmitter for single-pass transmissometers). The test may also include the mounting flanges normally supplied with the opacity monitor. Conduct the AOP test using the procedures in either 6.3.12 or 6.3.13.

6.3.12 *Option 1*—Use a photodetector (*1*) that is less than 3 cm wide relative to the direction of movement, (*2*) that is preferably of the same type and has the same spectral response as the photodetector in the transmissometer, (*3*) that is capable of detecting 1 % of the peak response, and (*4*) that does not saturate at the peak illuminance (that is, when aligned at the center position of the light beam. Use an appropriate data recorder to record continuously the photodetector response during the test.

6.3.12.1 Perform this test in a dark room. If the external photodetector output is measured in a dc-coupled circuit, measure the ambient light level in the room (must be <0.5 % of the peak light intensity to accurately define the point at which 2.5 % peak intensity occurs). If the external photodetector is measured in an ac-coupled configuration, demonstrate that (*1*) ambient light level in the room, when added to the test light beam, does not cause the detector to saturate, and (*2*) turning on and off the ambient lights does not change the detected signal output. Include documentation for these demonstrations in the report.

6.3.12.2 Position the photodetector on the horizontal arc 26 cm from the projected beam centerline (5°) and record the response. Move the photodetector along the arc at ≤2.5-cm intervals (or rotate the turntable in ≤0.5° increments) until a position 26 cm (5°) on the opposite side of the arc is reached. Record the response for each measurement location and over the full test range; continue recording data for all positions up to 26 cm (5°) even if no response is observed at an angle of ≤26 cm (5°) from the centerline.

6.3.12.3 Repeat the AOP test on an arc in the vertical direction relative to the normal orientation of the detector housing.

6.3.12.4 For both the horizontal and vertical directions, calculate the relative response of the photodetector as a

function of projection angle (response at each measurement location as a percentage of the peak response). Determine the maximum projection angle for the horizontal and vertical directions yielding a response greater than 2.5 % of the peak response. Determine conformance to the specification in 6.3.2. Report these angles as the angle of projection. Report the relative angle of projection curves in both the horizontal and vertical directions.

6.3.13 *Option 2*—Use this test procedure for only transmissometer designs that have previously met the AOP specification using Option 1 procedure during the preceding 12 months. Ensure that the light beam is focused at the actual flange-to-flange separation distance of the transmissometer.

6.3.13.1 Perform this test in a darkened room. Project the light beam onto a target located at a distance of 3 m from the transceiver/transmitter. Focus the light beam on the target.

6.3.13.2 Measure the beam dimensions (for example, diameter) on the target in both the horizontal and vertical directions. Calculate the maximum total angle of projection (that is, total subtended angle) based on the separation distance and beam dimensions. Compare this result to the previously measured AOP result obtained using Option 1. If the AOP results obtained by Option 1 and Option 2 do not agree within ±0.3°, repeat the test using Option 1.

6.3.13.3 Report the greater AOV result of Option 1 or Option 2 as the AOV for the test instrument.

6.4 *Insensitivity to Supply Voltage Variations*:

NOTE 9—The purpose of this design specification is to ensure that the accuracy of opacity monitoring data is not affected by supply voltage variations over ±10 % from nominal or the range specified by the manufacturer, whichever is greater. This specification does not address rapid voltage fluctuations (that is, peaks, glitches, or other transient conditions), emf susceptibility or frequency variations in the power supply.

6.4.1 *Test Frequency*— See 6.1.2.

6.4.2 *Specification*— The opacity monitor output (measurement and calibration check responses, both with and without compensation, if applicable) must not deviate more than ±1.0 % single pass opacity for variations in the supply voltage over ±10 % from nominal or the range specified by the manufacturer, whichever is greater.

6.4.3 *Design Specification Verification Procedure*:

6.4.3.1 Determine the acceptable supply voltage range from the manufacturer's published specifications for the model of opacity monitor to be tested. Use a variable voltage regulator and a digital voltmeter to monitor the rms supply voltage to within ±0.5 %. Measure the supply voltage over ±10 % from nominal, or the range specified by the manufacturer, whichever is greater.

6.4.3.2 Set-up and align the opacity monitor (transceiver and reflector for double-pass opacity monitors, or transmitter and receiver for single-pass opacity monitors) at a measurement pathlength of 3 m. Use a pathlength correction factor of 1.0. Calibrate the instrument using external attenuators at the nominal operating voltage. Insert an external attenuator with a nominal value between 10 and 20 % single-pass opacity into the measurement path and record the response. Initiate a calibration check cycle and record the low level and upscale responses.

6.4.3.3 Do not initiate any calibration check cycle during this test procedure except as specifically required. Decrease the supply voltage in increments of 2 % of the nominal value and record the one-minute or more frequent measurement response to the attenuator at each voltage (after the instrument response has stabilized) until the minimum value is reached. Initiate a calibration check cycle at the minimum supply voltage and record the low level and upscale responses. Reset the supply voltage to the nominal value and then increase the supply voltage in increments of 2 % of the nominal value and record the measurement response to the attenuator at each voltage (after the instrument response has stabilized) until the maximum value is reached. Initiate a calibration check cycle at the maximum supply voltage and record the low level and upscale responses, both with and without compensation, if applicable.

6.4.3.4 Determine conformance to specifications in 6.4.2.

6.5 *Thermal Stability*:

NOTE 10—The purpose of this design specification is to ensure that the accuracy of opacity monitoring data is not affected by ambient temperature variations over the range specified by the manufacturer.

6.5.1 *Test Frequency*— See 6.1.3. Repeat this test anytime there is a major change in the manufacturing process or change in a major component that could affect thermal stability.

6.5.2 *Specification*— The opacity monitor output output (measurement and calibration check responses, both with and without compensation, if applicable) must not deviate more than ±2.0 % single pass opacity for every 22.2°C (40°F) change in ambient temperature over the range specified by the manufacturer.

6.5.3 *Design Specification Verification Procedure*:

6.5.3.1 Determine the acceptable ambient temperature range from the manufacturer's published specifications for the model of opacity monitor to be tested. Use a climate chamber capable of operation over the specified range. If the climate chamber cannot achieve the full range (for example, cannot reach minimum temperatures), clearly state the temperature range over which the opacity monitor was tested and provide additional documentation of performance beyond this range to justify operating at lower temperatures.

6.5.3.2 Set-up and align the opacity monitor (transceiver and reflector for double-pass opacity monitors, or transmitter and receiver for single-pass opacity monitors) at a measurement pathlength of 3 m. Use a pathlength correction factor of 1.0. If the opacity monitor design introduces purge air through the housing that contains optical components of the transceiver, transmitter, or detector, operate the purge air system during this test. If the purge air does not contact internal optics and electronics, the air purge system need not be operative during the test.

NOTE 11—For double-pass systems with reflectors that can be shown to be insensitive to temperature, this test may be performed using a zero reference similar to an external zero jig, but one that is designed specifically to evaluate the temperature stability of the instrument for this test. This device must be designed to be temperature invariant so that the test evaluates the stability of the instrument, not the stability of the zero reference. Another acceptable approach is to construct a test chamber where the reflector is mounted outside the chamber at a constant temperature. The control unit, if applicable, need not be installed in the

climate chamber if it is to be installed in a controlled environment by the end user.

6.5.3.3 Establish proper calibration of the instrument using external attenuators at a moderate temperature that is, 21.1 ± 2.8°C (70 ± 5°F). Insert an external attenuator with a single-pass value between 10 and 20 % opacity into the measurement path and record the response. Initiate a calibration check cycle and record the low level and upscale responses.

NOTE 12—Grid filters are recommended for these tests to eliminate temperature dependency of the attenuator value.

6.5.3.4 Do not initiate any calibration check cycle during this test procedure except as specifically stated. Continuously record the temperature and measurement response to the attenuator during this entire test. Decrease the temperature in the climate chamber at a rate not to exceed 11.1°C (20°F) per hour until the minimum temperature is reached. Note data recorded during brief periods when condensation occurs on optical surfaces due to temperature changes. Allow the opacity monitor to remain at the minimum temperature for at least one hour and then initiate a calibration check cycle and record the low level and upscale responses with and without compensation, if applicable. Return the opacity monitor to the initial temperature and allow sufficient time for it to equilibrate and for any condensed moisture on exposed optical surfaces to evaporate. Increase the temperature in the climate chamber at a rate not to exceed 11.1°C (20°F) per hour until the maximum temperature is reached. Allow the opacity monitor to remain at the maximum temperature for at lest one hour and then initiate a calibration check cycle and record the low level and upscale responses.

NOTE 13—The notations when condensation occurs are for explanatory purposes only.

6.5.3.5 Determine conformance to specifications in 6.5.2.

6.6 *Insensitivity to Ambient Light*:

NOTE 14—The purpose of this design specification is to ensure that opacity monitoring data are not affected by ambient light.

6.6.1 *Test Frequency*— See 6.1.3. Repeat this test anytime there is a major change in the manufacturing process or change in a major component that could affect the opacity monitor sensitivity to ambient light.

6.6.2 *Specification*— The opacity monitor output (measurement and calibration check responses, both with and without compensation, if applicable) must not deviate more than ±2.0 % single pass opacity when exposed to ambient sunlight over the course of a day.

6.6.3 *Design Specification Verification Procedure*:

6.6.3.1 Perform this test (*1*) at a time of maximum insolation, on a clear day where light scattering from atmospheric haze, clouds, or particulate matter are at a minimum, (*2*) when at least one 1-h solar radiation average is ≥900 W/m ^{2}, and (*3*) for a specific opacity monitor that has successfully completed the spectral response, thermal stability tests, and other design specification verification procedures.

6.6.3.2 Set-up the opacity monitor outside, with the light path in a horizontal position, and where it will be directly exposed to sunlight for the entire day. Use mounting flanges of normal length, and attach the flanges to mounting plates that extend at least 0.305 m (12 in.) above, below, and to both sides of the mounting flanges. Paint the interior surfaces of the mounting flanges and the facing surfaces of the mounting plates white. Optically align the opacity monitor (transceiver and reflector for double-pass opacity monitors, or transmitter and receiver for single-pass opacity monitors) at a measurement pathlength of 3 m on an approximate east-west axis aligned with the transit of the sun. Use a pathlength correction factor of 1.0. Calibrate the instrument using external attenuators prior to the test. Insert an external attenuator with a single-pass value between 10 and 20 % opacity into the measurement path and record the response. Initiate a calibration check cycle and record the low level and upscale responses.

6.6.3.3 Use a cosine corrected total solar radiation monitor that (*1*) is capable of detecting light from 400 to 1100 nm, (*2*) has been calibrated under natural daylight conditions to within ±5 % against industry standards, (*3*) has a sensitivity of at least 90 μA/100 W/m ^{2}, and (*4*) has a linearity with a maximum deviation of less than 1 % up to 3000 W/m^2. Place the solar radiation monitor on top of the transceiver for double-pass opacity monitors, or detector for single-pass opacity monitors. If weather covers are supplied with all opacity monitors, install the solar radiation monitor on top of the weather cover. Measure the total solar radiation according to the manufacturer's instructions.

6.6.3.4 Continuously record the opacity monitor response to the attenuator and the output of the solar radiation monitor for a period from two hours before sunrise to two hours after sunset. Record the ambient temperature during this period. Do not conduct calibration check cycles during this test more frequently than once per 24-h period or the longest interval recommended in the manufacturer's published specifications. Document and report the frequency of conducting calibration check cycles during the insensitivity to ambient light test.

6.6.3.5 If necessary, correct the measurement data for changes in instrument response due to ambient temperature variation by running a separate test with the same instrument shielded from the sunlight. Determine the maximum percent deviation in the measurement response for any six minute period during the test.

6.6.3.6 Determine conformance with the specifications 6.6.2.

6.7 *External Audit Filter Access*:

NOTE 15—The opacity monitor design must accommodate independent assessments of the measurement system response to commercially available external (that is, not intrinsic to the instrument) audit filters. These calibration attenuators may be placed within the mounting flange, air purge plenum, or other location after the projected light beam passes through the last optical surface of the transceiver or transmitter. They may also be placed in a similar location at the other end of the measurement path prior to the light beam reaching the first optical surface of the reflector or receiver. The external audit filter access design must ensure (*a*) the filters are used in conjunction with a zero condition based on the same energy level, or within 5 % of the energy reaching the detector under actual clear path conditions, (*b*) the entire beam received by the detector will pass through the attenuator, and (*c*) the attenuator is inserted in a manner that minimizes interference from the reflected light.

6.7.1 Insert the external audit filter into the system.

6.7.2 Determine whether the entire beam received by the detector passes through the attenuator and that interference from reflected light is minimal.

6.7.3 Determine whether the zero condition corresponds to the same energy level reaching the detector as when actual clear path conditions exist

6.8 *External Zero Device—Optional*:

NOTE 16—The opacity monitor design may include an external, removable device for checking the zero alignment of the transmissometer. Such a device may provide an independent means of simulating the zero opacity condition for a specific installed opacity monitor over an extended period of time and can be used by the operator to periodically verify the accuracy of the internal simulated zero device. The external zero device must be designed: (*1*) to simulate the zero opacity condition based on the same energy level reaching the detector as when actual clear path conditions exist; (*2*) to produce the same response each time it is installed on the transmissometer; and (*3*) to minimize the chance that inadvertent adjustments will affect the zero level response produced by the device. The opacity monitor operator is responsible for the proper storage and are of the external zero device and for reverifying the proper calibration of the device during all clear path zero alignment tests.

NOTE 17—The purpose of this design specification is to ensure that the external zero device design and mounting procedure will produce the same response each time that the device is installed on the transmissometer.

6.8.1 *Test Frequency*— If the optional external zero device is supplied with any opacity monitors of the subject model, select and perform this test for one representative external zero device manufactured each year for the opacity monitor model certified by this practice.

6.8.2 *Specification*— The opacity monitor output must not deviate more than ±1.0 % single pass opacity for repeated installations of the external zero device on a transmissometer.

6.8.3 *Design Specification Verification Procedure*—Perform this test using an opacity monitor that has successfully completed the tests to demonstrate insensitivity to ambient light (6.6) and which is set up and properly calibrated for a measurement pathlength of 3 meters. Install the external zero device and make any necessary adjustment to it so that it produces the proper zero opacity response from the test transmissometer. Remove the external zero device and return the test transmissometer to operation and verify that the opacity monitor output indicates 0.0 ± 0.5 % opacity. Without making any adjustments to the external zero device or the test opacity monitor, install and remove the external zero device five times. Record the zero response of the test opacity monitor to the external zero device and to the clear path condition after it is returned to operation after each installation.

6.8.4 Determine conformance with the design specification in 6.8.3.

6.9 *Calibration Check Devices*:

NOTE 18—Opacity monitors covered by this practice must include automated mechanisms to provide calibration checks of the installed opacity monitor.

6.9.1 *Simulated Zero Device*—Establish the proper response to the simulated zero device under clear path conditions while the transmissometer is optically aligned at the installation pathlength and accurately calibrated. Certify that the simulated zero device conforms to the following:

6.9.1.1 The simulated zero device produces a simulated clear path condition or low level opacity condition, where the energy reaching the detector is between 90 and 190 % of the energy reaching the detector under actual clear path conditions. Corrections for energy levels other than 100 % are permitted provided that they do not interfere with the instrument's ability to measure opacity accurately.

6.9.1.2 The simulated zero device provides a check of all active analyzer internal optics with power or curvature, all active electronic circuitry including the light source and photodetector assembly, and electric or electro-mechanical systems, and hardware and/or software used during normal measurement operation.

NOTE 19—The simulated zero device allows the zero drift to be determined while the instrument is installed on the stack or duct. Simulated zero checks, however, do not necessarily assess the optical alignment, status of the reflector (for double-pass systems), or the level of dust contamination of all optical surfaces.

6.9.2 *Upscale Calibration Device*—Certify that the device conforms to the following:

6.9.2.1 The upscale calibration device measures the upscale calibration drift under the same optical, electronic, software, and mechanical components as are included in the simulated zero check.

6.9.2.2 The upscale calibration device checks the pathlength corrected measurement system response where the energy level reaching the detector is between the energy levels corresponding to 10 % opacity and the highest level filter used to determine calibration error.

6.9.2.3 The upscale calibration check response is not altered by electronic hardware or software modification during the calibration cycle and is representative of the gains and offsets applied to normal effluent opacity measurements.

NOTE 20—The upscale calibration device may employ a neutral density filter or reduced reflectance device to produce an upscale drift check of the measurement system. The upscale calibration device may be used in conjunction with the simulated zero device (for example, neutral density filter superimposed on simulated zero reflector) or in a parallel fashion (for example, zero and upscale [reduced reflectance] devices applied to the light beam sequentially).

6.10 *Status Indicators*:

NOTE 21—Opacity monitors must include alarms or fault condition warnings to facilitate proper operation and maintenance of the opacity monitor. Such alarms or fault condition warnings may include lamp/source failure, purge air blower failure, excessive zero or calibration drift, excessive zero or dust compensation, and so forth.

6.10.1 Specify the conditions under which the alarms or fault condition warnings are activated.

6.10.2 Verify the conditions of activations in 6.10.1 on an annual basis.

6.10.3 Certify the that the system's visual indications, or audible alarms, as well as electrical outputs can be recorded as part of the opacity data record and automatically indicate when either of the following conditions are detected:

6.10.3.1 A failure of a sub-system or component which can be reasonably expected to invalidate the opacity measurement, or

6.10.3.2 A degradation of a subsystem or component which requires maintenance to preclude resulting failure.

6.11 *Pathlength Correction Factor (PLCF) Security*:

NOTE 22—The opacity monitoring system must display and record all measured opacity values (including effluent opacity measurements, zero and upscale calibration checks, and zero or dust compensation values) corrected to the emission outlet pathlength.

6.11.1 Certify that the system has been designed and constructed so that the value of the pathlength correction factor

6.11.1.1 Cannot be changed by the end user, or

6.11.1.2 Is recorded during each calibration check cycle, or

6.11.1.3 The system must provides an alarm when the value is changed from the certified value.

6.11.2 Document the option(s) that are selected and write corresponding instructions. Provide them to the end user to minimize the likelihood that the PLCF will be changed inadvertently.

6.12 *Measurement Output Resolution*:

6.12.1 Certify that the opacity monitor output, including visual measurement displays, analog outputs, or digital outputs, or combinations thereof, have a resolution ≤0.5 % opacity over the measurement range from –4.0 % opacity to 50 % opacity or higher value.

NOTE 23—The 0.5 % opacity resolution is required for determining calibration error or achieving conformance with applicable regulatory requirements.

6.13 *Measurement and Recording Frequency*:

6.13.1 Certify that each opacity monitor is designed and constructed to do the following:

6.13.1.1 To complete a minimum of one cycle of sampling and analyzing for each successive 10-s period.

6.13.1.2 To calculate average opacity values from 6 or more data points equally spaced over each 1-min period included in the average (for example, 6 measurements per 1-min average or 36 measurements per 6-min average),

6.13.1.3 To record values for each averaging period.

NOTE 24—Most regulations require recording of six-min average opacity values, however, some regulatory agencies require calculation of one-minute or other less than 6-min average values.

7. Procedure—Manufacturer's Performance Specifications

7.1 *Required Performance Tests*—Test each instrument prior to shipment to ensure that the opacity monitor meets manufacturer's performance specifications for instrument response time, calibration error, and optical alignment sight performance. Conduct a performance check of the spectral response for each instrument.

NOTE 25—These tests are performed for the specific transmissometer components (transceiver and reflector for double-pass opacity monitors or transmitter and receiver for single-pass opacity monitors), the specific control unit (if included in the installation), and any other measurement system components that are supplied by the manufacturer. The data recording system that will be employed by the end user is not required to be evaluated by these tests. Additional field tests are necessary to evaluate the complete opacity monitoring system after it is installed at the end user's facility. The field test procedures may be simplified when certain conditions are met in the conduct of the manufacturer's performance specification tests.

7.2 *Representative Test Conditions*:

7.2.1 Conduct the manufacturer's performance specification tests under conditions that are representative of the specific intended installation, whenever possible. Obtain from the end user accurate information about the installation pathlength (that is, flange-to-flange separation distance), monitoring pathlength, emission outlet pathlength, and the applicable opacity standard. Use the applicable opacity standard, monitoring pathlength, and emission outlet pathlength to select appropriate attenuators for the calibration error test and to establish the pathlength correction factor for the opacity monitor being tested. Set-up and test the transmissometer components at the same installation pathlength and the same pathlength correction factor as that of the field installation.

NOTE 26—When these conditions are met, the equivalent *clear path* setting for an external zero device can be established in conjunction with the manufacturer's calibration error test. This device can then be used in subsequent field calibration error tests to verify performance of the opacity monitor. If both the actual installation pathlength and the pathlength correction factors are within ±10 % of the values used for the manufacturer's calibration error test, the manufacturer's calibration error test results are valid and representative for the installation.

7.2.2 If actual pathlength values differ by >2 %, but ≤10 % relative to that used for the manufacturer's calibration error test, repeat the zero alignment (for installation pathlength errors) or reset the pathlength correction factor (for pathlength correction errors) prior to subsequent opacity monitoring.

NOTE 27—A field performance audit may be substituted for the field calibration error test when the above criteria are satisfied.

7.2.3 If the actual installation pathlength and pathlength correction factors exceed ±10 % of the values used for the manufacturer's calibration error test, repeat the calibration error test.

7.3 *Default Test Conditions*—If the installation pathlength, monitoring pathlength, and emission outlet pathlength cannot be determined by the manufacturer (for example, opacity monitor is intended for future resale, opacity monitor will serve as backup for multiple installations, construction of facility is not complete and so forth), test the opacity monitor at an installation pathlength of 5 m and use a pathlength correction factor of 1.0. If an opacity monitor is designed for a range of measurement pathlengths that does not include 5 m, test the opacity monitor at the middle of the range specified by the manufacturer (see example in Note 28). If the applicable opacity standard cannot be determined, assume a standard of 20 % opacity for the selection of attenuators used for the calibration error test.

NOTE 28—Example: If an opacity monitor is designed for measurement pathlengths from 6 to 12 m, use a pathlength of 9 m.

7.4 *Test Set-Up*—Conduct the performance tests of the opacity monitor in a clean environment in an area protected from manufacturing or other activities that create dust, mist, fumes, smoke, or any other ambient condition that will interfere with establishing a clear path opacity condition.

7.4.1 Set-up the transmissometer components on test stands that will facilitate adjustments to, and maintenance of, the optical alignment throughout the test procedure.

7.4.2 Use the appropriate installation pathlength as determined from 7.2, if possible, or 7.3, if necessary.

7.4.3 Adjust the focus of the transmissometer for the

installation pathlength, if applicable.

7.4.4 Optically align the transmissometer components according to the written procedures of the manufacturer.

7.4.5 Verify that the alignment sight indicates proper alignment.

7.4.6 Enter the proper pathlength correction factor (if applicable) for the opacity monitor.

7.4.7 Establish proper calibration of the measurement system according to the manufacturer's written procedures.

7.4.8 Connect the opacity monitor to an appropriate data recorder for documenting the performance test results. At a minimum, use a data recorder that

7.4.8.1 Is capable of resolving 0.25 % opacity,

7.4.8.2 Has been accurately calibrated and verified according to the manufacturer's QA procedures, and

7.4.8.3 Has a sufficiently fast response to measure the instrument response time.

7.5 *Selection of Calibration Attenuators*—Using the applicable pathlength correction factor and opacity standard values from 7.2 (if possible) or 7.3 (if necessary), select calibration attenuators that will provide an opacity monitor response corrected to single-pass opacity values for the emission outlet pathlength in accordance with the following:

Applicable Standard	10 to 19 % opacity	≥20 % opacity
Low level:	5 to 10 %	10 to 20 %
Mid level:	10 to 20 %	20 to 30 %
High level:	20 to 40 %	30 to 60 %

NOTE 29—The manufacturer may elect to use additional calibration attenuators in the calibration error test. The use of additional calibration attenuators may be advantageous in demonstrating the linear range of the measurement system. Alternate calibration attenuator values may be used where required by applicable regulatory requirements (for example, state or local regulations, permit requirements, and so forth).

7.6 *Attenuator Calibrations*—Calibrate the attenuators used for the manufacturer's calibration at the frequency and according to the procedures specified in 40 CFR 60, Appendix B, Performance Specification 1, 7.1.3. For transmissometers operating over narrow bandwidths, determine the attenuator calibration values for the actual operating wavelengths of the transmissometer.

7.7 *Instrument Response Time*:

NOTE 30—The purpose of the instrument response time test is to demonstrate that the instantaneous output of the opacity monitor is capable of tracking rapid changes in effluent opacity, using the instantaneous output or signal input used to generate averages. It includes the transmissometer components and the control unit if one is included for the particular installation. The instrument response time test does not include the opacity monitoring system permanent data recorder. (A separate field test should be conducted to verify the ability of the system to properly average or integrate and record 6-min opacity values.)

7.7.1 *Specification*— The instrument response time must be less than or equal to 10 s.

7.7.2 *Instrument Response Time Test Procedure* —Using a high-level calibration attenuator, alternately insert the filter five times and remove it from the transmissometer light path.

7.7.2.1 For each filter insertion and removal, determine the amount of time required for the opacity monitor to display 95 % of the step change in opacity on the data recorder used for the test. For upscale response time, determine the time it takes to reach 95 % of the final, steady upscale reading. For downscale response time, determine the time it takes for the display reading to fall to 5 % of the initial upscale opacity reading.

7.7.2.2 Calculate the mean of the five upscale response time measurements and the mean of the five downscale response time measurements. Report each of the scale and downscale response time determinations and the mean upscale and downscale response times.

7.7.3 Determine conformance with the specification in 7.7.1. If the response time is not acceptable, take corrective action and repeat the test.

7.8 *Calibration Error*:

NOTE 31—The calibration error test is performed to demonstrate that the opacity monitor is properly calibrated and can provide accurate and precise measurements.

7.8.1 *Specification*— The calibration error must be ≤3 % opacity as calculated ad the sum of the absolute value of the mean difference and confidence coefficient for each of three test attenuators.

7.8.2 *Calibration Error Test Procedure*:

7.8.2.1 Zero the instrument. Insert the calibration attenuators (low-, mid- and high-level) into the light path between the transceiver and reflector (or transmitter and receiver).

7.8.2.2 While inserting the attenuator, ensure that the entire beam received by the detector passes through the attenuator and insert the attenuator in a manner that minimizes interference from the reflected light.

NOTE 32—See also Note 15. The placement and removal of the attenuator must be such that measurement of opacity is performed over a sufficient period to obtain a stable response from the opacity monitor.

7.8.2.3 Make a total of five non-consecutive readings for each filter. Record the opacity monitoring system output readings in single-pass percent opacity.

7.8.2.4 Subtract the single-pass calibration attenuator values corrected to the stack exit conditions from the opacity monitor responses. Calculate the arithmetic mean difference, standard deviation, and confidence coefficient of the five measurements value. Calculate the calibration error as the sum of the absolute value of the mean difference and the 95 % confidence coefficient for each of the three test attenuators. Report the calibration error test results for each of the three attenuators.

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{4}$$

where:

x = arithmetic mean,
x_i = individual measurements, and
n = number of data points.

$$S_d = \sqrt{\frac{\sum_{i=1}^{n} x_i^2 - \frac{(\sum_{i=1}^{n} x_i)^2}{n}}{n-1}} \tag{5}$$

where:

s_d = standard deviation.

$$CC = t_{0.975}\frac{S_d}{\sqrt{n}} \tag{6}$$

where:

$t_{0.975}$ = t-value ($t_{0.975}$ = 2.776 for n = 5), and
CC = confidence coefficient

7.8.2.5 Determine conformance with the specification in 7.8.1. If the calibration error test results are not acceptable, take corrective action, recalibrate the opacity monitor according to the manufacturer's written instructions, and repeat the calibration error test.

7.9 *Optical Alignment Indicator – (Uniformity of Light Beam and Detector)*:

NOTE 33—Each transmissometer must provide a means for visually determining that the instrument is optically aligned. The purpose of this specification is to ensure that the alignment device is capable of clearly indicating when the transmissometer components are misaligned. The performance test procedure will also detect opacity monitors where the accuracy of opacity measurements is adversely affected by the use of the light beams having non-uniform intensity, or the use of non-uniform detectors, or inefficient or poor quality retro-reflector material.

7.9.1 *Specification*— The alignment sight must clearly indicate that the unit is misaligned when an error of ±2 % single-pass opacity occurs due to shifts in the optical alignment of the transmissometer components. For opacity monitor designs that include automatic beam steering (that is beam position sensing and an active means for adjusting alignment so that centered alignment is maintained even with slowly changing misalignment conditions), an alarm must be activated when the alignment is varied beyond the manufacturer's specified range of angular tolerance is unable to maintain alignment.

NOTE 34—Modifications of the alignment indicator test procedures for systems with beam steering are included in 7.9.7.

7.9.2 *Alignment Indicator Performance Test Procedure*— Conduct the alignment indicator test according to the procedures in 7.9.3-7.9.7.

NOTE 35—The test procedure can be modified to accommodate moving of either component of the transmissometer to achieve equivalent geometric misalignment as described in 7.9.3-7.9.6. Alignments tests may be performed in the horizontal or vertical planes of the instrument and the instrument components may be turned on their side to accommodate the tests.

7.9.3 *Set-up*:

7.9.3.1 Set up the transmissometer on test stands that allow adjustments for the rotational and translational misalignment tests.

7.9.3.2 Optically align the transceiver and reflector (double-pass opacity monitor) or transmitter and receiver (single-pass opacity monitor) according to the manufacturer's written instructions. Verify that all alignment indicator devices show proper alignment.

7.9.3.3 Conduct the alignment indicator performance test with a clear path condition. Alternatively, insert an external attenuator that produces a response ≤10 % single-pass opacity into the measurement path turn it approximately 3° from normal to the light path to eliminate surface reflection, and record the indicated opacity.

7.9.4 *Case 1: Single and Double Pass Opacity Monitors*:

7.9.4.1 Slowly tilt the transceiver (double-pass opacity monitor) or transmitter (single-pass opacity monitor) upward in the vertical plane (for example, adjust the appropriate alignment bolts or mounting mechanism) relative to the reflector (double-pass opacity monitor) or receiver (single-pass opacity monitor) until an error of ±2 % opacity is first indicated on the data recorder. Verify that the alignment indicator shows misalignment.

7.9.4.2 Illustrate and record the alignment indicator and the degree of misalignment shown.

7.9.4.3 Return the system to its aligned condition.

7.9.4.4 Repeat the entire procedure by tilting the transceiver in the opposite (downward) direction.

7.9.4.5 Repeat the rotational misalignment check of the transceiver or transmitter in the horizontal plane (both to the left and right) and again illustrate and record the visual depiction of the alignment for each step of the procedure.

7.9.5 *Case 2, Single-Pass Opacity Monitors Only*

7.9.5.1 Slowly tilt the receiver in the vertical plane (for example, adjust the appropriate alignment bolts or mounting mechanism) until an error of ±2 % opacity is first indicated on the data recorder, Verify that the alignment indicator shows misalignment.

7.9.5.2 Illustrate and record the alignment indicator and the degree of misalignment shown.

7.9.5.3 Return the system to its aligned condition and again draw the alignment indicator.

7.9.5.4 Repeat the entire procedure by tilting the receiver in the opposite direction.

7.9.5.5 Repeat the rotational misalignment check of the receiver in the horizontal plane (both to the left and right) and again illustrate and record the visual depiction of the alignment for each step of the procedure.

7.9.6 *Case 3: Single and Double Pass Opacity Monitors*:

7.9.6.1 Achieve lateral misalignment of the transceiver or transmitter relative to the reflector or receiver by slowly moving either assembly linearly to the left until a positive or negative error of ±2 % opacity is first indicated on the data recorder. Verify that the alignment indicator shows lateral misalignment of the transceiver or transmitter relative to reflector or receiver.

7.9.6.2 Illustrate and record the alignment indicator and the degree of misalignment shown.

7.9.6.3 Return the system to its aligned condition and again draw the alignment indicator.

7.9.6.4 Repeat the entire procedure by moving the same component to the right.

7.9.6.5 Repeat the test in the vertical plane (both above and below the aligned position) and again illustrate and record the visual depiction of the alignment for each step of the procedure.

7.9.7 *Assessment*—Determine conformance with the specification in 7.9.1.

NOTE 36—The performance of the alignment indicator is acceptable if: (*1*) for each case of rotational or translational misalignment, misalignment is clearly shown when an error of ±2 % single-pass opacity first occurs in each direction, and (*2*) proper alignment status is consistently indicated when the opacity monitor is optically aligned. A clear indication of misalignment is one that is objectively apparent relative to reference marks or conditions; an alignment device that requires a subjective judgement of the degree of misalignment is not acceptable.

7.9.8 *Automatic Beam Steering*:

7.9.8.1 If the design includes automatic beam steering, investigate each case of rotational and translational misalignment. Vary the alignment over the manufacturer's specified range of angular tolerance for which the alignment is maintained and for which the opacity is maintained within ±2 % single pass opacity.

7.9.8.2 During each misalignment test, record the angular misalignment where the alarm is activated.

7.9.8.3 Determine conformance with the specification in 7.9.2.

NOTE 37—Acceptable performance is indicated if (*1*) the alarm is activated or misalignment is clearly show at, or before, the angular tolerance specified by the manufacturer is reached, and (*2*) for translational misalignment, an alarm is activated or misalignment is clearly shown at, or before, an error of ±2 % single-pass opacity first occurs in each direction.

7.10 *Special Response Performance Check*:

NOTE 38—This performance check provides a simple method to ensure that the special response of each instrument satisfies the spectral response design specifications of 6.2. The performance check uses a photopic transmission filter placed in the measurement beam and comparison with a range of expected responses determined from Monitor-Specific Performance Check Limits (6.2.7).

7.10.1 *Specification*— The transmissometer response to the photopic transmission filter used to establish performance check limits, after correction of the response to account for the applicable pathlength correction factor, must be within ±2 % opacity of the range defined by the maximum and minimum responses (determined in 6.2.7 in units of percent opacity.

7.10.2 *Spectral Response Performance Check Procedure*:

7.10.2.1 Insert the photopic transmission filter used to establish the performance check limits into the opacity monitor measurement beam after the calibration error test has been completed. Record the opacity monitor response to the photopic filter in units of percent opacity.

7.10.2.2 Correct the opacity monitor response to the equivalent value corresponding to a pathlength correction factor of 1.

7.10.2.3 Compare the corrected response to the acceptable limits and determine conformance with the specification in 7.10.1.

7.10.2.4 If an unacceptable result is obtained, do not assume that the spectral response design requirements are met. Investigate the causes for an unacceptable result. Unless a clear explanation of the problem is apparent, repeat Spectral Response Design Specifications Verification Procedure (6.2.3) and recalibrate the photopic filter.

7.11 *Calibration Device Value and Repeatability*:

NOTE 39—The purpose of this specification is to verify that the upscale calibration device response is repeatable and provides results consistent with the use of external filters. This specification may also be applied to additional internal calibration check devices (values), if provided in the instrument.

7.11.1 *Specification*— The 95 % confidence coefficient for repeated measurements of the upscale calibration device must be less than 1.5 % opacity. The upscale calibration device must be assigned a value relative to the calibration error test results for the specific opacity monitor.

7.11.2 *Calibration Device Repeatability Test Procedure*— Perform this procedure immediately after successfully completing the calibration error test for the opacity monitor. Do not make any adjustments to the opacity monitor until after this procedure has been completed. Make seven non-consecutive measurements of each internal device and record the opacity monitor responses.

7.11.2.1 Calculate the 95 % confidence coefficient using the same procedures as that used in the calibration error test. (See 7.8.2.4).

7.11.2.2 Determine conformance to the specification in 7.11.1.

7.11.2.3 Assign values to the upscale calibration device(s) relative to the calibration error test results. Construct a calibration curve by linear regression analysis through zero of the results of the calibration error test (x-axis are correct values and y-axis are the corresponding opacity monitor responses). Using the mean of the five measurement responses for each upscale calibration device as the y-axis value, determine in corresponding x-axis value from the calibration curve. Assign this value to the internal upscale calibration device.

8. Quality Assurance Guidelines for Opacity monitor Manufacturers

8.1 *General*—The products shall be manufactured under a quality program that ensures that like products, subsequently made, have the same reliability and quality as those originally examined to determine compliance with this design specification. To establish and maintain such a program, the manufacturer shall be guided by industry practice, its quality controls, and by this set of guidelines. These guidelines are supported by various standards and by industry practice.

8.1.1 *Applicable Documents*—This document is an adaptation of and the referred to the following standards for additional guidance:

ISO/DIS 9004 Quality Management and Quality System Elements-Guidelines

ANSI/NCSL Z 540-1-1994, Calibration Laboratories and Measuring Equipment - General Requirements

8.1.2 *General Vocabulary*—Terms used in this document are defined by:

ISO 842, Quality Vocabulary

8.2 *Quality System*:

8.2.1 *Management Responsibility*:

8.2.1.1 *Quality Policy*— The management of a company shall develop and promulgate a corporate quality policy. Management shall ensure that the corporate policy is understood, implemented and maintained.

8.2.1.2 *Quality Objectives*—Based on this policy, key quality objectives shall be defined, such as fitness for use, performance, reliability, safety, and so forth.

8.2.1.3 *Quality Management Systems*—A documented system shall be developed, established and implemented for the product as a means by which stated quality policies and objectives can be realized. The quality system should ensure that: (*1*) it is understood and effective; (*2*) products actually do satisfy customer expectations; (*3*) emphasis is placed on problem prevention rather than dependence on detection after

occurrence; (*4*) causes, not only symptoms, of a problem are found, and that corrections are comprehensive, touching any activity that has a bearing on quality; and (*5*) feedback is generated that can be used at the product or process design stage for correcting problems and improving product. Management shall provide the resources essential to the implementation of quality policies and objectives.

8.2.2 *Quality System Documentation and Records*—The elements requirements and provisions adopted for the quality management system shall be documented in a systematic and orderly manner.

8.2.2.1 Documentation shall be legible, clean, readily, identifiable and maintained in an orderly manner.

8.2.2.2 The quality management system shall establish and require the means for identification, collection, filing, storage, maintenance, retrieval and disposition of pertinent quality documentation and records. Methods shall be established for making changes, modifications, revisions or additions to the contents of applicable documentation in a controlled manner.

8.3 *Corrective Action Program*:

8.3.1 *Introduction*— There shall be a comprehensive defect analysis/corrective action program for reporting and following-up on product and program deficiencies.

8.3.2 *Assignment of Responsibility*:

8.3.2.1 The responsibility and authority for instituting corrective action shall be defined as part of the quality system.

8.3.2.2 The coordination, recording and monitoring of corrective action shall be assigned to a specific person or group within the organization. (The analysis and execution of any corrective action may involve a variety of people from such areas as sales, design, production engineering, production and/or quality control.)

8.3.3 *Deficiencies*:

8.3.3.1 Deficiencies shall be evaluated in terms of their potential impact on product quality, reliability, safety, performance and customer satisfaction.

8.3.3.2 The relationship between cause and effect should be determined. The root cause should be determined before planning and implementing corrective measures. Careful analysis shall be given to the product and all related processes, operations, records, and so forth.

8.3.3.3 Controls of processes and procedures shall be implemented to prevent recurrence of the problem. When the corrective measures are implemented, their effect shall be monitored in order to ensure desired goals are met.

8.3.3.4 Permanent changes resulting from corrective action shall be incorporated into the work instructions, manufacturing processes, product specifications and/or the quality manual.

8.4 *Quality System Certification*—Companies with ISO 9001/9002 certification, companies meeting the requirements of ANSI/ASQC Q90 (Q91 or Q92), companies meeting the requirements of nationally recognized test laboratories (NRTLs) where the manufactured product bears the mark (or marks) of the NRTL(s), or companies with an equivalent independently and periodically verified quality system, and which adopt this specification as part of their product definition shall be deemed to meet all of the above quality assurance guidelines. Companies meeting these conditions shall attach the applicable certification to the manufacturer's certification of conformance report as proof of such designation.

9. Report

9.1 Summarize the design and performance (see Table 1, Table 2 and Table 3) data in the report. See Fig XI.1 for an example.

9.2 Include all descriptive information, such as:

9.2.1 Manufacturer or supplier information,

9.2.2 Opacity monitor information,

9.2.3 User information, and

9.2.4 Installation information.

10. Keywords

10.1 continuous opacity monitor; design specification; performance specification; transmissometer

APPENDIX

(Nonmandatory Information)

X1. DATA SUMMARY FORM

X1.1 Fig. X1.1 is an example data form to summarize data to certify conformance with design and performance specifications.

This document is provided by <u>(company name)</u>, an <u>(original manufacturer, supplier, remanufacturer, or service facility)</u>, of/for opacity monitoring systems that are intended to comply with standards of performance established by the US EPA 40CFR60, Appendix B, Performance Specification 1, Performance Specifications for Opacity Monitors. This EPA specification references the above ASTM Standard Practice, which may be used by the manufacturer or supplier to demonstrate that the designated opacity monitor meets those performance requirements that can be tested and verified by the supplier prior to field installation. Data in this summary document (Part I) have been generated in compliance with the procedures and specifications shown in the ASTM Standard Practice, SPXXXX. These data confirm that the designated opacity monitor meets or exceeds the requirements of this Standard Practice.

I. MANUFACTURER/SUPPLIER INFORMATION

Company name ______________________________

Location ____________________________________

II. OPACITY MONITOR INFORMATION

Model________________________

Transceiver type ________________

Transceiver serial no. ____________

Reflector type __________________

Reflector serial no. ______________

Control unit serial no. ____________

Software version no. _____________

III. USER INFORMATION

Company ___________________________________

Plant ____

Process/boiler _______________________________

Location ____________________________________

IV. INSTALLATION INFORMATION

Monitoring pathlength (depth of effluent) ________

Installation pathlength (flange to flange) ________

Emission outlet pathlength (stack exit) _________

PLCF or (OPLR) _________

Facility opacity standard, % opacity ____________

FIG. X1.1 Data Summary Form

PART I—DESIGN AND PERFORMANCE SPECIFICATIONS-TESTED AT MANUFACTURER'S FACILITY

Conformance with design specifications is demonstrated by testing two separate opacity monitors, each of which is representative of standard production. One opacity monitor is selected and tested annually and the other is selected from either a production lot of instruments not to exceed 20 in size, or from monthly production, and tested in accordance with procedures described in the SPXXXX. The tests associated with each of the above selected analyzers is required to be repeated anytime there is a critical component change that is substantial, hardware or software change, or manufacturing process change that could affect performance with respect to said design specifications. The test data derived from each of the above two described analyzers is summarized below.

1. Design Specifications Verified Through Tests Prescribed For An Annually, or More Often, Selected Opacity Monitor

The opacity monitor that tested to demonstrate the following design parameters was selected on the basis of an annual selection ____ , or following a major change in the design or construction of the monitor ____.

OPACITY MONITOR INFORMATION
Model____________________
Transceiver type ______________
Transceiver serial no. __________
Reflector type _______________
Reflector serial no. ___________
Control unit serial no. __________
Software version no. ___________

TESTS PERFORMED BY:
________________________________ DATE: _________________

TEST DATA REVIEWED AND CERTIFIED BY:
________________________________ DATE: _________________

1.1 *Spectral Response*

Data listed below were obtained by calculation ____, or by actual measurement using a monochrometer ____. A description of either the calculations or the measurement test setup are included in Attachment A.

Parameter	Specification	Actual Test Result
Peak response	Between 500-600 nm	
Mean response	Between 500-600 nm	
Max response beyond 700 nm	Less than 10% of peak	
Max response less than 400 nm	Less than 10% of peak	

FIG. X1.1 Data Summary Form *(continued)*

1.2 *Thermal Stability*

Parameter	Specification	Actual Test Result
Tested range, min temp	Mfgr specified, °C (°F)	
Tested range, max temp	Mfgr specified, °C (°F)	
Nominal measurement value	0-10% opacity	
Measurement drift, max deviation from nominal measurement value	≤ 2% opacity/40 °C (°F)	
Zero drift from nominal without compensation	≤ 2% opacity/40 °C (°F)	
Zero drift from nominal with compensation	≤ 2% opacity/40 °C (°F)	
Span drift from nominal without compensation	≤ 2% opacity/40 °C (°F)	
Span drift from nominal with compensation	≤ 2% opacity/40 °C (°F)	

1.3 *Insensitivity to Ambient Light*

Parameter	Specification	Actual Test Result
Max solar intensity	900 W/m^2	
Nominal measurement value	0-10% opacity	
Measurement drift, max deviation from nominal measurement value	≤ 2% opacity	
Drift was corrected for thermal effects, yes or no	Mfgr specified	
Zero drift from nominal without compensation	≤ 2% opacity	
Zero drift from nominal with compensation	≤ 2% opacity	
Span drift from nominal without compensation	≤ 2% opacity	
Span drift from nominal with compensation	≤ 2% opacity	

1.4 *Calibration Device Availability*

Parameter	Specification	Availability/Value
External zero device	Optional	
Ext zero device repeatability	≤ 1% opacity	
External filter access	To be available	

FIG. X1.1 Data Summary Form *(continued)*

1.5 *Zero/upscale calibration check apparatus*

Parameter	Specification	Test Result
Indicated response to simulated zero calibration device	0 ± 0.5% opacity	
Simulated Zero Check	Simulated condition during which the energy reaching the detector is between 90 and 190% of the energy reaching the detector under actual clear path conditions *	
Response to upscale calibration device without electronic hardware or software modification	+10% opacity to highest calibration error attenuator value	
Does automatic zero and span calibration devices check all active optics and electronics?	Required	
Is automatic correction provided for zero drift?	Mfgr to specify (Y/N)	
	If yes, specify freq	
Is automatic correction provided for dust accumulation on exposed optics?	Mfgr to specify (Y/N)	
	If yes, specify freq	
Is automatic correction provided for span/cal drift?	Mfgr to specify (Y/N)	
	If yes, specify freq	

Note: * Negative opacity values of this magnitude can be calculated from the detector or preamplifier output by measuring the equivalent optical energy detected in the clear path condition and that produced by the zero calibration check device.

1.6 *PLCF (OPLR) Security Precautions*

Condition	Specification	As Supplied (Y/N)
Original certified value is fixed and not adjustable by user	One or more of listed conditions to be provided	
Value is output with zero and span values during each calibration cycle	One or more of listed conditions to be provided	
Flag (alarm) is activated when changed from original certified or permanently recorded value	One or more of listed conditions to be provided	

FIG. X1.1 Data Summary Form *(continued)*

1.7 ***Faults and Alarm (Mfgr to specify)***

Fault Conditions (Note 1&3)	Specified Indication	Actual Indication
Conditions tested	Audible or visual, and electrical	Tested output
	Same	
	Same	
	Same	
Alarm Conditions (Note 2&3)	**Specified Indication**	**Actual Indication**
Conditions tested	Audible or visual, and electrical	Tested output
	Same	
	Same	
	Same	
	Same	
	Same	

Note 1) Fault conditions are those conditions which, when they occur, are deemed by the manufacturer to result in performance which is not in compliance with this performance specification.
Note 2) Alarm conditions are those conditions for which the manufacturer recommends review and/or corrective action by trained service personnel as appropriate to prevent further deterioration of instrument performance which could result in performance not in compliance with this specification.
Note 3) Manufacturer may use other nomenclature to designate either general or specific alarms and/or faults, as long as they are appropriately defined in the operators manual.

1.8 ***Miscellaneous***

Parameter	Specification	Test Result
Resolution of visual measurement indication, if provided	≤ 0.5% opacity	
Resolution of analog output measurement indication	≤ 0.5% opacity	
Resolution of serial digital output, if provided	≤ 0.5% opacity	
Bipolar range of visual measurement indication	+50% opacity or more to -4% opacity or less	
Capability of analog output measurement indication to indicate negative values to at least -4% opacity	Required	
Are means available to monitor daily zero and span drift before correction?	Optional	
Is span drift corrected for zero drift in above method?	Optional	
Are means available to monitor dust accumulation on exposed optical surfaces?	Optional	

FIG. X1.1 Data Summary Form *(continued)*

What surfaces are monitored for dust accumulation?	Mfgr to specify, if applicable	
Is an alarm provided for excessive dust accumulation?	Mfgr to specify, if automatic correction is provided	
What level of dust accumulation triggers the above alarm?	Mfgr to specify, if applicable	
Is dust level measured separately from the accumulative zero drift?	Mfgr to specify	
Are all dust (if provided), zero, and span values corrected to stack exit conditions?	Required	
What is the normal update interval for opacity measurements?	10 sec max	
Do longer term opacity averages include at least 6 approximately equaly distributed individual measurement values per minute?	Required	

FIG. X1.1 Data Summary Form *(continued)*

2. Design Specifications Verified Through Tests Prescribed for an Opacity Monitor Selected on a Monthly Basis, or From Each Production Lot

The opacity monitor that was selected and tested to demonstrate the following design parameters was selected on the basis of a monthly selection ____, a manufacturing lot not to exceed 20 in size ____, or following a major change in the design or construction of the monitor ____.

OPACITY MONITOR INFORMATION

Model ____________________
Transceiver type ____________________
Transceiver serial no. ____________
Reflector type ____________________
Reflector serial no. ____________
Control unit serial no. ____________
Software version no. ____________

TESTS PERFORMED BY:

______________________________ DATE: ______________

TEST DATA REVIEWED AND CERTIFIED BY:

______________________________ DATE: ______________

2.1 *Angle of View*

Transmissometer is exempt from angle of view specification because the angle of projection has been demonstrated to be less than______degrees.

Portion of opacity monitor included in the test: ______________________________

Portion of opacity monitor excluded in the test: ______________________________

Light source used in the test: directional _____, or non-directional _____
Were detector/measurement electronics modified to measure response to designated light source: (Y/N) _______. If so, describe modifications in attachment B.

Parameter	Specification	Actual Test Result
Angle of view, horizontal	$\leq 4°$ for all radiation providing a response of $\geq 2.5\%$ of peak response	
Angle of view, vertical	$\leq 4°$ for all radiation providing a response of $\geq 2.5\%$ of peak response	

FIG. X1.1 Data Summary Form *(continued)*

2.2 *Angle of Projection*

Transmissometer is exempt from angle of projection specification because the angle of projection has been demonstrated to be less than______degrees.

Option 1 Procedure
Portion of opacity monitor included in the test:______________________________

____

Portion of opacity monitor excluded in the test: ______________________________

____

Photodetector used in test: ____

____ If tests were conducted with dc coupled measurement circuit, was ambient light level less than 0.5% of peak light intensity? (Y/N) _______

____ If tests were conducted with ac coupled measurement circuit, was it demonstrated that ambient light levels did not saturate the detector? (Y/N) ______; and was it demonstrated that turning on/off ambient lights did not affect measurements? (Y/N) ______.

Parameter	Specification	Actual Test Result
Angle of projection, horizontal	≤ 4° for all radiation providing a response of ≥ 2.5% of peak response	
Angle of projection, vertical	≤ 4° for all radiation providing a response of ≥ 2.5% of peak response	

Option 2 Procedure (For transmissometer designs that have previously met the AOP specification using Option 1 procedure during the preceding 12 months)
Distance from transceiver/transmitter to target _____________
Beam dimension (diameter) in the vertical direction ___________
Beam dimension (diameter) in the horizontal direction __________
Option 2 Result: (total subtended angle):___________ degrees.
Option 1 Result (angle of projection): _____________ degrees
Difference (Option 1 result minus Option 2 result) ___________ degrees. If the results do not agree within 0.3 degrees, repeat the test using Option 1.

FIG. X1.1 Data Summary Form *(continued)*

2.3 ***Insensitivity to supply voltage variations***

Manufacturers specified nominal voltage: __________
Manufacturers specified operating voltage range, if specified: __________________

Parameter	Specification	Actual Test Value
Min test voltage	-10% from nom, or mfgrs min specified operating voltage, whichever is lesser	
Max test voltage	+10% from nom, or mfgrs max specified operating voltage, whichever is greater	
Nominal measurement value	0-10% opacity	
Measurement drift, max deviation from nominal measurement value from nominal to max ac voltage	± 1% opacity	
Measurement drift, max deviation from nominal measurement value from nominal to min ac voltage	± 1% opacity	
Zero drift from nominal to min ac voltage without compensation	± 1% opacity	
Zero drift from nominal to min ac voltage with compensation	± 1% opacity	
Span drift from nominal to min ac voltage without compensation	± 1% opacity	
Span drift from nominal to min ac voltage with compensation	± 1% opacity	
Zero drift from nominal to max ac voltage without compensation	± 1% opacity	
Zero drift from nominal to max ac voltage with compensation	± 1% opacity	
Span drift from nominal to max ac voltage without compensation	± 1% opacity	
Span drift from nominal to max ac voltage with compensation	± 1% opacity	

FIG. X1.1 Data Summary Form *(continued)*

3. Performance Specifications Verified by Tests Prescribed for Each Specific Opacity Monitor.

The following tests were performed individually on the specific instrument described in the beginning of this test report. Further, the following signatures attest to the fact that the design and performance specifications tested on previous opacity monitors, as described in Sections 1 and 2, are representative of the design and performance of this specific monitor.

TESTS PERFORMED BY:

______________________________ DATE: ________________

TEST DATA REVIEWED AND CERTIFIED BY:

______________________________ DATE: ________________

3.1 ***Calibration error***

Filter	**Specify Group, Group I or II**	**Actual Filter Value**	**Specified Cal Error**	**Actual Cal Error**
Low	Group		3%	
Mid	Group		3%	
High	Group		3%	

Note: Group I filters are 5-10, 10-20, 20-40 percent opacity (low, mid, high)
Group II filters are 10-20, 20-30, 30-60 percent opacity (low, mid, high)

3.2 ***Misalignment indication***

This opacity monitor uses (a) manual alignment and visual alignment sighting device (Y/N) ____, or b) automatic beam steering (Y/N) ______.

3.2.1 *For manually aligned opacity monitors with visual alignment sighting indicator:*

A. Rotational misalignment

Parameter	**Specification**	**Test Result**
Nominal measurement value	0-10% opacity	
Indication of centered alignment	Acceptable? (Y/N)	
Clear indication of misalignment for rotational misalignment for transceiver/transmitter in upward vertical direction which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for rotational misalignment for transceiver/transmitter in downward vertical direction which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for rotational misalignment for transceiver/transmitter in horizontal right direction which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for rotational	Acceptable? (Y/N)	

FIG. X1.1 Data Summary Form *(continued)*

misalignment for transceiver/transmitter in horizontal left direction which causes 2% opacity change		

B. Lateral misalignment, same test conditions

Parameter	Specification	Test Result
Clear indication of misalignment for lateral movement to the left which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for lateral movement to the right which causes 2% opacity change	Acceptable? (Y/N)	
Clear indication of misalignment for lateral movement in upward direction which causes 2% opacity change Clear indication of misalignment with above movement	Acceptable? (Y/N)	
Clear indication of misalignment for lateral movement in downward direction which causes 2% opacity change Clear indication of misalignment with above movement	Acceptable? (Y/N)	

3.2.2 *For opacity monitors with automatic beam steering.*

Parameter	Specification	Test Result
Nominal measurement value	0-10% opacity	
Indication of centered alignment	Acceptable? (Y/N)	
Degree of rotational misalignment for transceiver/transmitter in upward vertical direction which triggers alarm	Mfgr to specify	
Degree of rotational misalignment for transceiver/transmitter in downward vertical direction which triggers alarm	Mfgr to specify	
Degree of rotational misalignment for transceiver/transmitter in horizontal right direction which triggers alarm	Mfgr to specify	
Degree of rotational misalignment for transceiver/transmitter in horizontal left direction which triggers alarm	Mfgr to specify	

FIG. X1.1 Data Summary Form *(continued)*

Parameter	Specification	Test Result
Lateral movement of transceiver/transmitter in upward vertical direction which causes an indication of misalignment	Mfgr to specify movement	
What is maximum deviation of opacity from nom when opacity monitor is misaligned as above from centered to value noted?	≤ 2% opacity	
Lateral movement of transceiver/transmitter in downward vertical direction which causes an indication of misalignment	Mfgr to specify movement	
What is maximum deviation of opacity from nom when opacity monitor is misaligned as above from centered to value noted?	≤ 2% opacity	
Lateral movement of transceiver/transmitter in horizontal right direction which causes an indication of misalignment	Mfgr to specify movement	
What is maximum deviation of opacity from nom when opacity monitor is misaligned as above from centered to value noted?	≤ 2% opacity	
Lateral movement of transceiver/transmitter in horizontal left direction which causes an indication of misalignment	Mfgr to specify movement	
What is maximum deviation of opacity from nom when opacity monitor is misaligned as above from centered to value noted?	≤ 2% opacity	

3.3 *Spectral Response Repeatability*

Date of photopic filter calibration ____________________
Peak transmission of photopic filter ____________________
Calculated nominal response of analyzer to photopic filter ____________________, % opacity
Calculated allowable variation of the response to photopic filter:
OP, high _______________, OP, low ____________________
Above opacity values converted to stack exit values according to the specific PLCF (OPLR) established for this installation: PLCF (OPLR) _______________
OPc, nom ____________, OPc, high _______________, OPc, low _______________
Actual measured response of the instrument to listed photopic filter _____________ % opacity
Is measured response within previously calculated range (Y/N) _____________

FIG. X1.1 Data Summary Form *(continued)*

3.4 ***Intrinsic opacity monitor settings/adjustments***

List all configurable parameters to obtain the performance described in this report. These parameters typically include calibration check intervals, calibration check correction, procedure settings relating to flange-to-flange separation distance, range, averaging time, alarms, etc.

4. Quality Assurance Program

4.1 ***ISO, ANSI/ASQC, or other Quality System Certification***

Is the company which prepared this report certified according to ISO quality standards, ANSI/ASQC (QC 90 or 91) or other applicable quality standard (Y/N) ____________. If so, to what classification _______________ and on what date _______________. Attach certificate of such designation as attachment C.

4.2 ***QA Guideline Compliance***

Has the company which prepared this document established and maintained a QA/QC program that is in compliance with the guidelines specified in the ASTM SPXXXXXX, (Y/N) ________. If so, please attach a description of the quality program in attachment C, and indicate the person responsible for the integrity of this quality program ________________________________

Suppliers who comply with 4.1 and not 4.2 are required to supply all supporting test data with this report.

FIG. X1.1 Data Summary Form *(continued)*